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CERVICAL HEADGEAR IN CLASS II DIVISION 1 CORRECTION IN CHILDREN

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ACADEMIC DISSERTATION

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"I have finished my work. It is as perfect as I can make it."

Edward Hartley Angle

(1855-1930)

To my grandchildren

CONTENTS

1. ABSTRACT

Class II division 1 malocclusion occurs in 3.5 to 13 percent of 7–12–year-old children, and is the most common reason for orthodontic treatment in Finland. There are several different treatment approaches to Class II correction. In Finland, Class II correction is most commonly performed using headgear treatment. The aim of this study was to investigate the effects of cervical headgear treatment on dentition, facial skeletal and soft tissue growth, and upper airway structure, in children.

Sixty-five schoolchildren were studied, 36 boys and 29 girls with a mean age of 9.3 (range 6.6 – 12.4) years at the onset of treatment. All the children were consequently referred to an orthodontist in Forssa because of Class II division 1 malocclusion, and they were treated by the author. The included children had protrusive maxilla indicated by an A point being in front of the Nasion-Pogonion line and an overjet of more than 2mm (3 to 11 mm). The children were treated with a Kloehn-type cervical headgear as the only appliance until Class I first molar relationships were achieved. The essential features of the headgear were cervical strong pulling forces, a long upward bent outer bow, and an expanded inner bow. Dental casts and lateral and posteroanterior cephalograms were taken before and after the treatment. The results were compared to a historical, cross-sectional Finnish control cohort or to historical, age- and sex-matched, normal Class I controls with analyzed dental casts and cephalograms. Posteroanterior cephalometric results were compared to a historical, cross-sectional Austrian control cohort.

The Class I first molar relationships were achieved in all the treated children. The mean treatment time needed was 1.7 (range 0.3-3.1) years. Phase 2 treatments were needed in 52% of the children, most often because of excess overjet or overbite. The treatment decreased maxillary protrusion by inhibiting alveolar forward growth, while the rest of the maxilla and mandible followed normal growth. Both SNA and ANB angles were decreased, and the maxillary A-point seemed to remain at virtually the same place without any forward movement. Despite the restricted forward growth of the maxilla at the level of the A-point, the length of the palatal plane (ANS-PNS) grew forward at a normal rate, but the palate was rotated anteriorly downward. The expansion of the inner bow of the headgear induced widening of the maxilla and the upper and lower dental arches. The widening of the maxilla was also seen as increased nasal width. Class II division 1 malocclusion was associated with narrower oro- and hypopharyngeal space than in the controls with a normal Class I molar relationship. The treatment increased the retropalatal airway space, while the rest of the airway remained unaffected. The facial profile was esthetically improved due to the Class II correction. Class II malocclusion was associated with larger SNA, ANB angles and skeletal facial convexity than was seen in the normal controls, while the facial convexity was decreased by the treatment. Facial soft tissue masked the facial skeletal convexity, and the soft tissue convexities in the treatment group did not differ significantly from those of the controls. The treatment decreased the upper lip protrusion, widened the nasolabial angle, and decreased the gap between the lips in their relaxed position.

In conclusion, the headgear treatment with the expanded inner bow may be used as an easy and simple method for Class II correction in growing children. The treatment has several desirable effects on the facial profile and the upper airways.

Keywords: cephalometry, face, headgear, orthodontic, malocclusion, Class II, orthodontics, corrective

2. LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals I-V. In addition, some unpublished data are presented.

I Kirjavainen M, Kirjavainen T, Haavikko K. Changes in dental arch dimensions by use of an orthopedic cervical headgear in Class II correction. Am J Orthod Dentofacial Orthop 111: 59-66, 1997.

II Kirjavainen M, Kirjavainen T, Hurmerinta K, Haavikko K. Orthopedic cervical headgear with an expanded inner bow in Class II correction. Angle Orthod 70: 317-325, 2000.

III Kirjavainen M, Kirjavainen T. Maxillary expansion in Class II correction with orthopedic cervical headgear. A posteroanterior cephalometric study. Angle Orthod 73: 281-285, 2003.

IV Kirjavainen M, Hurmerinta K, Kirjavainen T. Facial profile changes in early Class II correction with cervical headgear. Angle Orthod 77: 960-967, 2007.

V Kirjavainen M, Kirjavainen T. Upper airway dimensions in Class II malocclusion. Effects of headgear treatment. Angle Orthod 77: 1046-1053, 2007.

3. INTRODUCTION

Class II division 1 malocclusion and dental crowding are the two most common indications for orthodontic treatment in Finnish children at school age (Heikinheimo et al. 1987, Keski-Nisula et al. 2003). The Class II division 1 malocclusion may involve different dental and skeletal components. Dental malpositions, maxillary protrusion, and mandibular retrusion are among the possible causative factors.

Kloehn reported impressive results with a headgear treatment of Class II division 1 malocclusion in growing children already in 1947 (Kloehn 1947, Ricketts 2000). However, the timing of Class II correction before the pubertal growth spurt has remained controversial. At the onset of this study, there were different opinions on early treatment of Class II malocclusion also in Finland; most orthodontists preferred the use of functional appliances during the pubertal growth spurt or fixed appliance therapy in the permanent dentition with or without extraction of teeth.

In Finland, the health care system provides an outstanding possibility to follow up the development and maturation of occlusion, and allows intervention at any time during the growth period (Pietilä et al. 2008). The onset of treatment at an early age allows utilizing the remaining growth potential to manipulate the skeletal structures with simple and easy methods (Ghafari 1997, Gianelly and Valentini 1976, Graber 1969, King et al. 1990, Wieslander 1975). Cervical headgear is widely used as an early treatment appliance at the mixed dentition due to the easiness of the method and the good acceptance by children.

This thesis consists of five studies (I-V) evaluating the effects of cervical headgear therapy in Class II correction on dental arches, facial skeletal and soft tissue structures, and on upper airways. The headgear was used in growing children with the treatment onset between 6.6 and 12.4 years of age. The hypothesis was that the Class II correction could be achieved with the headgear treatment alone. The hypothesis was also that the claimed side effects of the treatment, such as distal tipping and extrusion of the upper first molars, as well as downward and backward rotation of the mandible (Baumrind et al. 1983, Baumrind et al. 1981, Baumrind et al. 1978, Klein 1957, Melsen 1978, Poulton 1967), may be avoided, if the headgear therapy is used with strong forces, a long, upward bent outer bow, and an expanded inner bow (Ricketts et al. 1979).

4. REVIEW OF THE LITERATURE

4.1 Definitions of normal occlusion and malocclusions

A classification of malocclusions, published by Angle in 1899, is still widely used perhaps because of its simplicity and clarity. Angle emphasized the importance of the sagittal relationships between the maxillary and the mandibular first molars regarding the occlusion and the interrelation of jaws. This molar relationship is one of the main criteria determining the class of the malocclusion. According to Angle's definition, in the normal occlusion, the upper first molars are distally positioned relative to the lower first molars. In intercuspal position, mesiobuccal cusps of the upper first molars should fall into the first lower molars' buccal groove. Angle considered all occlusions that were not ideal as malocclusions. In addition to the proper molar relationships, the concept of ideal occlusion included well-developed dental arches with evenly spaced teeth, incisal edges of the upper canines lying between the lower canines and first premolars, the upper incisors standing ahead of the lower incisors, and the lower incisors being in contact with the lingual surface of the upper incisors. The normal overjet, i.e. the horizontal overlap of the incisors, has been suggested to be 2 to 3 mm, and the normal overbite, i.e. the vertical overlap of the incisors, 1 to 2 mm (Proffit et al. 1993). In this classification, Angle ignored the facial proportions and esthetical aspects (Angle 1899, Angle 1906). Based on the occlusal relationship between the first molars, Angle defined three major classes of malocclusions (Tables 1 and 2).

Table 1. The original classification of malocclusions by Angle 1899

Class	Definition
I	Relative position of the dental arches mesio-distally normal, with malocclusions usually confined to the anterior teeth.
II	Retrusion of the lower jaw, with distal occlusion of the lower teeth.
Division 1	a) Narrow upper arch, with lengthened and prominent upper incisors; lack of nasal and lip function. Mouth breathers.
	b) Same as *a*, but with only one lateral half of the arch involved, the other being normal. Mouth breathers.
Division 2	a) Slight narrowing of the upper arch; bunching of the upper incisors, with overlapping and lingual inclination; normal lip and nasal function.
	b) Same as *a*, but with only one lateral half of the arch involved, the other being normal; normal lip and mouth function.
III	a) Protrusion of the lower jaw, with mesial occlusion of the lower teeth; lower incisors and cuspids inclined lingually.
	b) Same as *a*, but with only one lateral half of the arch involved, the other being normal.

Table 2. The currently used classification of malocclusions*

Class	Definition
I	The relationship between the molars in the upper and lower jaw is normal mesio-distal
II	The position of the mandibular molars is distal in relation to the maxillary molars, compared with normal occlusion
Subdivision 1	Protruding upper incisors
Subdivision 2	Receding upper incisors
III	The position of the mandibular molars is mesial in relation to the maxillary molars, compared with normal occlusion

* Adapted from Proffit et al. (1993)

4.1.1 Weaknesses of Angle's Classification

Angle's classification was criticized already soon after it was established (Andresen 1930, Case 1905, Lundström 1925). The three groups of malocclusions were designated neutral occlusion, distal occlusion and mesial occlusion (Björk 1947). Björk (1947) showed that many of the characteristics of malocclusions are evenly spread among the three classes of malocclusions. Despite its simplicity, Gravely and Johnson (1974) found surprisingly low inter-and intraexaminer reliability of the classification when performed by three experienced orthodontists in 102 study models and 80 school children: intraexaminer repeatability in defining Class II division 1 malocclusion ranged from 76 to 90%, while interexaminer reliability ranged from 59 to 77%. Appropriate kappa statistics were not calculated. Nonetheless, Angle's classification has remained the golden standard (Heikinheimo 1989, Myllärniemi 1970).

4.1.2 Development of the diagnostic methods of occlusion

In order to estimate the orthodontic treatment needs of malocclusion, and to determine the direction and the end-point of treatment, one needs to understand comprehensively the features of normal occlusion. The characteristics of normal occlusion have been widely studied (Andrews 1972, Hopkins and Murphy 1971, Moorrees et al. 1969, Poulton 1969, Weinstein et al. 1963). Several authors have described methods allowing estimation of the normality (Ackerman and Proffit 1969, Björk et al. 1964, Poulton and Aaronson 1961). Andrews (1972) defined normal occlusion by identifying six key elements: 1. the molar relationship, 2. the angulation, and 3. the inclination of the teeth crowns, 4. the rotation of the teeth, 5. the space conditions and the crowding of the teeth on dental arches, and 6. the type of occlusal plane (e.g. open or closed bite). Ramfjord and Ash (1966) emphasized the importance of analyzing the functionality of the occlusion and the supporting structures of teeth such as the jaws, temporomandibular joints, muscles, lips, and the tongue. They specified that the requirements of an ideal occlusion include: 1. a stable jaw relationship in centric relation, 2. a centric occlusion that is slightly in the front of the centric relation, 3. a straight protrusive movement between the centric relation and the centric occlusion, 4. an unrestricted glide with maintained occlusal contacts between the centric relation and the centric occlusion, and 5. an occlusal guidance in various excursions on the working rather than on the balancing side (Ramfjord and Ash 1971). More recent studies on occlusion attest to the importance of the functional analyses (Alanen and Varrela 1997, Heikinheimo et al. 1989, 1990, Helm and Petersen 1989).

Several systems have been developed to estimate the need for orthodontic intervention. Commonly used analyses include the Index of Orthodontic Treatment Need (IOTN) (Bearn et al. 1996, Shaw et al. 1991) and the Peer Assessment Rating (PAR) (Shaw et al. 1995). The IOTN classification incorporates the ranking of the significance of occlusal traits for dental health (the Dental Health Component, DHC) and the esthetic impairment (Aesthetic component, AC) (Bearn et al. 1996, Shaw et al. 1995, Shaw et al. 1991). In Finland, a 10-grade index has been developed based on Grainger's Treatment Priority Index (TPI) and is commonly used to determine whether an orthodontic intervention is needed (Grainger 1967, Heikinheimo 1989, Väkiparta et al. 2005). It is essential to note that these indices are designed for the permanent dentition and have been criticized for being unreliable and mainly useful for economic planning and cost-benefit estimations (Ferguson 2006).

4.1.3 Roentgen cephalometry

X-ray diagnostics and cephalometry are useful for defining the relationships between the skeletal, dental and soft tissue structures. The problem with cephalometrics is the lack of absolute reference points or planes to which the other structures could be compared. A further drawback in the use of a cephalometric imaging is the distortion of the structures. However, by standardizing the method it is possible to maintain comparability and reliability at an acceptable level. The first cephalostat that allowed standardized imagining was developed by Broadbent (1931). Subsequently, a number of different variants of the cephalostat were constructed, all of which were basically similar to that of Broadbent (Björk 1947). The use of roentgen cephalometry became widespread in orthodontic care already in the late 1940s (Ricketts 1981).

Downs (1948) stated that none of the individual measures is reliable as a reference, and he emphasized the use of angular relationships in the judgment of occlusion. Most of the reference points that are used today were described in the early 20th century. Subsequently, many different analyzing methods have been developed for the evaluation of the lateral cephalograms. Most of the analyses share similar features and use the same, or similar, reference points and measurements. The methods of lateral cephalometry used today, as summarized by Bosch and Athanasiou (1995) include: 1. Björk's analysis (Björk 1947), 2. Burstone's and coworkers' analysis for orthognathic surgery (Burstone et al. 1978), 3. Coben craniofacial and dentition analyses (Coben 1955, 1979), 4. Di Paolo's quadrilateral analysis (Di Paolo 1969, 1970, Di Paolo et al. 1983, 1984), 5. Downs' analysis (Downs 1948), 6. Farkas' and coworkers' analysis of inclinations of the facial profile (Farkas et al. 1985), 7. Harvold's analysis (Harvold 1974), 8. Hasund's (Bergen) analysis (Hasund 1977, Hasund et al. 1982), 9. Holdaway's analysis (Holdaway 1983, 1984), 10. Jarabak's analysis (Jarabak and Fizzell 1972), 11. Legan's and Burstone's soft tissue analysis for orthognathic surgery

(Legan and Burstone 1980), 12. McNamara's analysis (McNamara 1984), 13. Ricketts' analysis (Ricketts 1957, 1960, Ricketts et al. 1979), 14. Ricketts' comprehensive computer description analysis (Ricketts 1972, Ricketts et al. 1972), 15. Riedel's analysis (Riedel 1952), 16. Sassouni's analysis (Sassouni 1955, 1969, 1970), 17. Schwarz's analysis (Schwarz 1961), 18. Steiner's analysis (Steiner 1953, 1959), 19. Tweed's analysis (Tweed 1946, 1953), 20. Wits' appraisal (Jacobson 1975, 1976, 1988, 2003), 21. Worms' and coworkers' analysis (Worms et al. 1976), and 22. Wylie's analysis (Wylie 1947, Wylie and Johnson 1952).

One of the fundamental differences among the different cephalometric methods is related to the reference planes or structures that constitute the basis of the analysis. Brodie (1941) and Björk (1947) were the first to use Sella-Nasion-line, the anterior cranial base, as a reference line. Lundström and Lundström (1989) suggested that the Frankfort horizontal-line would be more accurate reference line than the Sella-Nasion-line.

Posteroanterior (PA) cephalography may be used to estimate and quantify facial asymmetries and structural skeletal abnormalities (Athanasiou and Van der Meij 1995, Ricketts 1981). However, the use of PA cephalography in orthodontic practice is rare, and hence, only a limited number of studies is available concerning this method. One of the problems with the posteroanterior cephalometry is the distorted proportions on imaging. Because of facial symmetry, the structures on lateral cephalometry may be considered to project onto the midsagittal plane. Hence, a single correction factor may be used. In contrast, in posteroanterior cephalometry, no such reference plane exits, and all the measurements should have their own correction factors. This problem has been solved using two different approaches: Athanasiou et al. (1992) have described measurements in comparison to the interorbital measurement, which is assumed to be stable, whereas Hsiao et al. (1997) implanted bullets to a dry skull, and defined correction factors for each measurement.

4.2 Description of Class II division 1 malocclusion

In Class II division 1 malocclusion, by definition, the lower first molars are backward or distal to the upper first molars, and the upper incisors are protrusive (Angle 1899, Angle 1906). Other features, often associated with this malocclusion, include enlarged overjet, the lower lip lying under the upper incisors and a short upper lip (Ricketts 1989a). Also an upper arch that is constricted in relation to the lower dental arch in the canine area, is an important feature of the malocclusion, and results in a peaked or narrow frontal dental arch (Ricketts 1989a). From the literature, it is obvious that Class II division 1 malocclusion may involve many different dental and skeletal components (Table 3). Nevertheless, although these are typical findings of Class II malocclusion, Bishara and associates (Bishara 1998a, Bishara et al. 1997) have claimed that such a generalized description of "the skeletal Class II" malocclusion is not diagnostically valid because the classification tells nothing about the size or the relationships of the jaws.

Maxillary protrusion and mandibular retrusion can both be associated with Class II malocclusion. Their apparent impact seems to depend on the analysis, and especially, on the reference line used. The sella to nasion line (SN) and the Frankfort horizontal line

(FrL) are both used as reference planes. If the sella to nasion line is used as a reference, maxillary protrusion is more often noted, whereas the use of the Frankfort horizontal line with the nasion perpendicular line (NP, McNamara line) as a reference seems often to emphasize mandibular retrusion. The related literature is summarized in Tables 4 and 5. Despite the multitude of these studies, meta-analyses have not been reported. It is worth noting that in addition to heterogenity of the analyses, most of these studies have other essential weaknesses such as small cohort sizes and lack a proper control cohort.

Table 3. Structural variations and categories of Class II division 1 malocclusion (Bishara et al. 1997, Fisk et al. 1953, Henry 1957)

Fisk et al. (1953)	
1.	Anteriorly positioned maxilla and teeth in relation to the cranium
2.	Anteriorly placed teeth in the maxilla
3.	Normal sized but posteriorly positioned mandible
4.	Underdeveloped mandible
5.	Posteriorly positioned mandibular teeth
6.	Various combinations of the five previous factors
Henry (1957)	
1.	Maxillary alveolar protrusion
2.	Maxillary basal protrusion
3.	Micromandible
4.	Mandibular retrusion
Bishara et al. (1997)	
1.	Maxillary skeletal protrusion with or without a long maxilla
2.	Maxillary dental protrusion
3.	Mandibular skeletal retrusion with or without a short mandible
4.	Mandibular dental retrusion
5.	Obtuse cranial base angle

In the literature, there is no consensus on the causes of Class II malocclusion. A long anterior cranial base and an obtuse cranial base angle, have been suggested to be among the etiologic factors of the development of Class II malocclusion (Björk 1947, Björk 1950, Elsasser and Wylie 1948, Rothstein and Yoon-Tarlie 2000). Rothstein and Yoon-Tarlie (2000) found enlarged frontal and maxillary sinuses with excessive anterior cranial base length in Class II division 1 malocclusions. However, Wilhelm et al. (2001) and Keski-Nisula et al. (2006) did not find a difference in the dimensions of the cranial base between children with Class II malocclusion and those with normal occlusion. These two studies support the idea that the structures and growth of the maxilla and mandible are linked to Class II occlusion than changes in the cranial base. The narrowness of the maxilla and the maxillary dental arch have been suggested to be the first signs of Class II malocclusion in the early deciduous dentition (Tollaro et al. 1996, Baccetti et al.1997, Varrela 1998). The maxillary narrowness may be the key factor in the development of Class II malocclusion, and it may lead to retrusion of the mandible (Keski-Nisula et al. 2006). The skeletal growth changes may have secondary adaptation to the narrow maxilla (McNamara 2000).

Table 4. Maxilla in Class II division 1 malocclusion (Altemus 1955, Antonini et al. 2005, Bishara et al. 1997, Blair 1954, Carter 1987, Craig 1951, Drelich 1948, Elsasser and Wylie 1948, Harris et al. 1972, Henry 1957, Hitchcock 1973, Hunter 1967, Johannsdottir et al. 1999, Keski-Nisula et al. 2006, Maj et al. 1960, McNamara 1981a, Pancherz et al. 1997, Renfroe 1948, Ricketts 1952, Riedel 1952, Riesmeijer et al. 2004, Rosenblum 1995, Rothstein and Yoon-Tarlie 2000).

Study	Year	Nation	N CII	M/F n	Controls M/F n	Age years	Study design L/C	Reference planes
Normal Maxilla								
Elsasser and Wylie	1948	US	93	45/48 F	93	5-23 F	C	SN, FrL
Craig	1951	US	36	17/19	34	12	C	S, FrL
Riedel	1952	US	38	–	76	7-36	C	SN, FrL
Blair	1954	US	40	–	40	10-14	C	SN, FrL
Maj et al.	1960	Italy	50	–	220	8-15	C	ANS-Bo
Hunter	1967	US	50	25/25	25	10.5-11.4	C	SN
Hitchcock	1973	US	109	52/57	40	7-28	C	SN
McNamara	1981	US	277	153/124	0	8-10.9	C	FrL, NP
Carter	1987	UK	30	15/15	0	10-19	L	SN
Bishara et al.	1997	US	30	15/15	35	5-12	L	SN, FrL
Pancherz et al.	1997	Germany, Sweden	345	172/173	H	8-13	C	SN
Johannsdottir et al.	1999	Iceland	32	16/16	200	5.6-7.7	C	SN, FrL
Keski-Nisula et al.	2006	Finland	137	137	44	4-7.8	C	FrL, NP
Protrusive Maxilla								
Drelich	1948	US	24	11/13	24	9-16	C	SN, FrL
Elsasser & Wylie	1948	US	93	45/48 M	93	5-16 M	C	SN, FrL
Ricketts	1952	US	50	18/32	6/11	12	C	SN, FrL
Altemus	1955	US	20	0/20	20	11.2-15.3	C	FrL
Henry	1957	Australia	103	13*	37	9-14.8	C	SN
Rosenblum	1995	US	103	36/67	H	11-16	C	SN, FrL
Rothstein & Yoon-Tarlie	2000	US	335	171/164	136/137	8.5-15.5	C	SN, K-WP
Riesmeijer et al.	2004	US, Netherlands	39-129	39-74/47-129	59-67/43-123	7-14	L	SN
Antonini et al.	2005	Italy	17	11/6	13/17	5.6-7.9	L	SN
Retrusive Maxilla								
Renfroe	1948	US	36	–	43	–	C	SN
Harris et al.	1972	US	63	–	96	10-12	C	SN
Henry	1957	Australia	103	–	37	9-14.8	C	SN

*Thirteen thumbsuckers, ANS = anterior nasal spine, Bo = Bolton point, C = cross-sectional, F = only in females, FrL = Frankfort horizontal line, H = historical controls, K-WP = Krogman-Walker plane = occipitale-maxillon line, L = longitudinal, M = only in males, NP = Nasion perpendicular (McNamara line), SN = Sella-Nasion line.

During the past few decades, there has been a significant tendency toward the development of narrower maxillary transverse dimensions in childhood (Defraia et al. 2006, Lindsten et al. 2001). Without any intervention and maxillary widening, this interarch discrepancy is expected to increase with age (Mills et al. 1978, Ricketts 1960, McNamara 2000). A narrow maxilla has been associated with mouth breathing (Bresolin et al. 1983, Gross et al. 1994, Linder-Aronson 1979), adaptation to colder climatic conditions (Huggare et al. 1993), weaker biting forces (Ingervall and Helkimo 1978, Kiliaridis 1995, Kiliaridis et al. 1989), sucking habits (Ogaard et al. 1994), and softer diets (Beecher et al. 1983, Watt and Williams 1951, Yamamoto 1996). It has been claimed that genetic factors would be of importance in the development of Class II occlusion (Nakasima et al. 1982). However, more recent sib and twin studies have shown that the genetic component in the etiology of Class II occlusion is low at best (Townsend et al 1988, Harris and Johnson 1991). The significance of the environmental influences is further emphasized by findings showing that Class II occlusion became part of the human occlusal variation only recently, during the last few centuries (Corruccini 1984, Varrela 1990).

Table 5. Mandible in Class II division 1 malocclusion (Adams 1948, Altemus 1955, Antonini et al. 2005, Baldridge 1941, Bishara et al. 1997, Blair 1954, Carter 1987, Craig 1951, Drelich 1948, Elsasser and Wylie 1948, Gilmore 1950, Harris et al. 1972, Henry 1957, Hitchcock 1973, Hunter 1967, Johannsdottir et al. 1999, Keski-Nisula et al. 2006, Maj et al. 1960, McNamara 1981a, Pancherz et al. 1997, Renfroe 1948, Ricketts 1952, Riedel 1952, Riesmeijer et al. 2004, Rosenblum 1995, Rothstein and Yoon-Tarlie 2000).

Study	Year	Nation	N CII	M/F	Controls M/F n	Age y	Study design L/C	Reference planes
Normal mandible								
Adams	1948	US	*	–	*	–	C	OP
Elsasser and Wylie	1948	US	93	45/48 M	93	5-16 M	C	SN, FrL
Blair	1954	US	40	–	40	10-14	C	SN, FrL
Altemus	1955	US	20	0/20	20	11.2-15.3	C	FrL
Maj et al.	1960	Italy	50	–	220	8-15	C	ANS-Bo
Rosenblum	1995	US	103	36/67	H	11-16	C	SN, FrL
Bishara et al.	1997	US	30	15/15	35	5-12	L	SN, FrL
Rothstein & Yoon-Tarlie	2000	US	335	171/164	136/137	8.5-15.5	C	SN, K-WP
Riesmeijer et al.	2004	US, Netherlands	39-129	39-74/47-129 M	59-67/43-123	7-14	L	SN
Antonini et al.	2005	Italy	17	11/6	13/17	5.6-7.9	L	NS
Retrusive mandible								
Baldridge	1941	US	33	–	58	–	C	SN
Drelich	1948	US	24	11/13	24	9-16	C	SN, FrL
Elsasser & Wylie	1948	US	93	45/48 F	93	5-23 F	C	SN, FrL
Renfroe	1948	US	36	–	43	–	C	SN
Gilmore	1950	US	67	37/30	31/30	16-42	C	SN
Craig	1951	US	36	17/19	34	12	C	S, FrL
Riedel	1952	US	38	–	76	7-36	C	SN, FrL
Ricketts	1952	US	50	18/32	6/11	12	C	SN, FrL
Henry	1957	Australia	103	–	37	9-14.8	C	SN
Hunter	1967	US	50	25/25	25	10.5-11.4	C	SN
Harris et al.	1972	US	63	–	96	10-12	C	SN
Hitchcock	1973	US	109	52/57	40	7-28	C	SN
McNamara	1981	US	277	153/124	0	8-10.9	C	FrL, NP
Carter	1987	UK	30	15/15	0	10-19	L	SN
Pancherz et al.	1997	Germany, Sweden	345	172/173	H	8-13	C	SN
Johannsdottir et al.	1999	Iceland	32	16/16	200	5.6-7.7	C	SN, FrL
Riesmeijer et al.	2004	US, Netherlands	39-129	39-74/47-129F	59-67/43-123	7-14	L	SN
Keski-Nisula et al.	2006	Finland	137	–	44	4-7.8	C	FrL, NP
Short mandible								
Elsasser & Wylie	1948	US	93	45/48 F	93	5-23 F	C	SN, FrL
Drelich	1948	US	24	11/13	24	9-16	C	SN, FrL
Gilmore	1950	US	67	37/30	31/30	16-42	C	SN
Craig	1951	US	36	17/19	34	12	C	S, FrL
Henry	1957	Australia	103	–	37	9-14.8		SN
Hunter	1967	US	50	25/25	25	10.5-11.4	C	SN
Keski-Nisula et al.	2006	Finland	137	–	44	4-7.8	C	FrL, NP
Long mandible								
Altemus	1955	US	20	0/20	20	11-15	C	FrL

*All studied 140 cases, ANS = anterior nasal spine, Bo = Bolton point, C = cross-sectional, F = only in females, FrL = Frankfort horizontal line, H = historical controls, K-WP = Krogman-Walker plane = occipitale-maxillon line, L = longitudinal, M = only in males, NP = Nasion perpendicular (McNamara line), OP = Occlusal plane, SN = Sella-Nasion line.

4.2.1 The maxillary and mandibular incisors and molar positions in Class II malocclusion

Incisors. One factor, suggested to be associated with the development of Class II malocclusion, is the position of the maxillary incisors relative to the maxillary skeletal structures. Riedel (1952) observed that the distance between the maxillary incisors and the facial plane (N-Pg) was twice as long in subjects with the Class II malocclusion as in the controls. In the study by McNamara (1981a), maxillary dental protrusion was less obvious, and in most cases, the mandibular canines were in normal position. However, some cases of mandibular dental retrusion and protrusion were observed.

Molars. Altemus (1955) observed that the maxillary posterior dentition in teenage girls with Class II malocclusion was mesially positioned. However, Baldridge (1950) and Elsasser and Wylie (1948) did not observe any differences in the position of the maxillary molars between individuals with Class I and Class II occlusions.

4.3 The natural course of Class II malocclusion

4.3.1 Class II division 1 malocclusion in the deciduous dentition

Occlusal features. It has been suggested that one of the key features in the development of Class II malocclusion is a narrow maxilla. In a longitudinal study of 25 children with Class II malocclusion who were followed from the age of five onwards, Baccetti et al. (1997) noted an average interarch transverse discrepancy due to a maxillary dental arch that was narrow relative to the mandible. Early signs of Class II malocclusion have also been seen already in deciduous dentition in other longitudinal studies (Antonini et al. 2005, Bishara et al. 1988, Varrela 1998). These signs have included: 1) distal step of the second deciduous molars, 2) distal deciduous canine relationship, and 3) excessive overjet and overbite.

Deciduous molar relationship. A flush relationship of the deciduous second molars has been reported to occur in about half of all children (Arya et al. 1973, Carlsen and Meredith 1960). Bishara et al. (1988, 1997) found in their longitudinal studies that 44% of these children would develop Class II occlusion in the permanent dentition. The more mesially positioned the mandibular deciduous molars are, the less likely is the development of Class II malocclusions in the permanent dentition (Bishara et al. 1988). The probability of the development of a Class II or end-to-end first molar relationship in the permanent dentition is 44% with flush terminal plane relationship in the deciduous dentition, 23% with the deciduous lower molars being 1 mm mesial to the upper deciduous molars, and only 13% if the lower deciduous molars are 2 mm or more mesially positioned in relation to the upper deciduous molars (Bishara et al. 1988). However, more mesial positioning of the deciduous lower molars may precede the development of Class III malocclusion in the permanent dentition.

Distal step (Class II) relationship. Several longitudinal studies have indicated that a distal step relationship in the second deciduous molars, which corresponds to Class II malocclusion in the permanent dentition, leads to a Class II molar relationship at the mixed dentition and also in the permanent dentition (Arya et al. 1973, Baccetti et al. 1997, Bishara et al. 1988, Frölich 1961, 1962). Bishara et al. (1988) noted that a Class

II malocclusion in the deciduous dentition seems never to be self-correcting in growing children. Varrela (1997) and Keski-Nisula et al. (2003) suggested that a flush terminal plane together with a Class II canine relationship in the deciduous dentition most likely predict Class II malocclusion in the permatent dentition.

Skeletal features. There are only few studies on the skeletal features of Class II malocclusion in the deciduous dentition and the results have been variable. Baccetti et al. (1997) observed a retruded and shorter mandible in the children who developed Class II malocclusion than in controls. Varrela (1993, 1998) noted normal maxilla, but a mandible with larger gonial angle and shorter corpus than in the controls. Retrusion of the mandible was observed at the age of five years and this skeletal feature became more evident from the age of five to seven years. Antonini et al. (2005) reported that sucking habits appeared to promote the skeletal maxillary protrusion. This maxillary protrusion was established early in the deciduous dentition and remained unmodified in the transition to the mixed dentition. The mandibular dimensions of the subjects with Class I and Class II occlusions did not show any significant differences at this stage of growth. In addition, in the passage from the deciduous through the mixed dentition, the growth increments were similar (Antonini et al. 2005).

4.3.2 Class II division 1 malocclusion in the mixed dentition

Occlusal Class II features. Consistently with the findings of Bishara et al. (1988), Baccetti et al. (1997) showed that typical occlusal Class II features, seen in the deciduous dentition, were maintained or exacerbated in the mixed dentition. These features included: 1) distal step of lower molars, 2) Class II deciduous canine relationship, 3) excessive overjet and overbite, and 4) transverse interarch discrepancy with narrow maxillary arch.

Permanent first molar relationship. The occlusion of the permanent first molars is determined by the terminal plane relationships of the deciduous second molars (Carlsen and Meredith 1960), of which the flush molar relationship is the most prevalent (Arya et al. 1973, Carlsen and Meredith 1960). Arya et al. (1973) found that the cusp-to-cusp first molar relationship was labile. In 70% of cases, the permanent first molars, which erupted into the cusp-to-cusp relationship, were converted to Class I first molar relationships. The remaining 30% of children ended up with a Class II relationship. The first permanent molars, which erupted into a full cusp mesial or distal relationship, maintained this relationship (Arya et al. 1973).

The leeway space. When the deciduous molars are replaced by permanent premolars, extra space is created, called “the leeway space”. This is particularly the case in the lower jaw due to the relatively larger mesio-distal size of the lower second deciduous molars as compared to the succeeding permanent premolars (Nance 1947a). This extra space gained in the lower jaw has been thought to support the development of occlusion with a normal first molar relationship from a flush molar relation (Moorrees and Chadha

1965, Nance 1947a, 1947b). However, a more recent study by Bishara et al. (1988) does not support this concept.

Skeletal features. Baccetti et al. (1997) found that in the transition from the deciduous to the mixed dentition, there was significantly greater maxillary forward growth and increased maxillary protrusion in the children with Class II malocclusion than in the controls. Class II malocclusion was associated with restricted mandibular growth and back- and downward rotation of the mandibular condyle. Stahl et al. (2008) observed in a longitudinal study, that increases in the mandibular length were significantly smaller in subjects with Class II division 1 malocclusion than in normal controls; while otherwise the craniofacial growth was normal. The growth did not correct the deficiency in the total mandibular length and ramus height in the children with Class II malocclusion. On the contrary, the difference from normal children increased during the pubertal growth spurt. Giuntini et al. (2008) studied the position of the glenoid fossa in nine-year-old children with Class II malocclusion associated with normal size retruded mandible in the mixed dentition. Children with Class II malocclusion had a significantly more distal position of the glenoid fossa than the Class I normal control children. Antonini et al. (2005) noted that the maxilla showed a significant forward position, whereas the mandibular position, dimensions and growth features in the children with Class II malocclusion were very similar to those in children with Class I occlusion. However, only the Class II children with sucking habits were studied. This may have influenced the results.

4.3.3 Development of vertical dimensions in Class II malocclusion

Abnormal vertical facial heights are common in the Class II malocclusion. In the deciduous dentition, Varrela (1993, 1998) observed shorter lower facial heights in 3- to 7-year-old children with Class II features than in controls. Altemus (1955) observed an increased vertical dysplasia in Class II division 1 malocclusion in teenage girls. Henry (1957) and Hunter (1967) noted a larger mandibular plane angle and increased facial heights in their subjects with Class II malocclusion. McNamara (1981a) observed a wide variation in the vertical development in children with Class II malocclusion; about half of the children exhibited excessive vertical development. In contrast to all other studies, Bishara et al. (1997) showed that vertical dimensions were shorter in children with Class II division 1 malocclusion than in controls. Although subsequent to this the growth pattern was normal, the aberrance in the vertical dimensions was maintained.

4.3.4 Soft tissue relationship of Class II division 1 malocclusion

There are only few studies concerning the soft tissue profile changes in Class II malocclusion. Bishara et al. (1997) observed in a longitudinal study that in Class II malocclusion, the skeletal convexity decreased but the lip protrusion and the soft tissue convexity increased with age from deciduous dentition to permanent dentition.

Hoffelder et al. (2007) have described changes in the soft tissue profile in children with Class II malocclusion between the ages of 6 to 16. The nose showed increase in thickness and length, upper lips tented to reduce (girls) but upper lip length showed a minor increase. Lower lip showed a moderate increase in all measurements. The soft tissues of the chin increased in both thickness and length. However, these results were not compared to any control cohort.

4.4 Respiratory pattern in children with Class II division 1 malocclusion

Linder-Aronson and Bäckström (1960) did not find a direct relationship between mouth breathing and the type of occlusion, not even in relation to overbite and overjet. However, children with long, narrow faces had greater nasal resistance, which correlated with an increased mandibular plane angle. During breathing through the mouth, the retrolingual airway is often kept open by bending the position of the head up - and backward. The position of the tongue appeared to be lower in mouth breathers (Linder-Aronson 1970). After adenoidectomy, the mandibular plane angle decreased by 4º, which is 2º more than in the controls (Linder-Aronson 1970). McNamara (1981b) described children with mouth breathing to have a narrow, V-shaped maxillary arch, with high palatal vault, protrusive upper incisors, and a Class II occlusal relationship.

Upper airway obstruction is rarely significantly manifested during wakefulness, but during sleep, breathing may be compromised. Most typically, this occurs in REM sleep. The prevalence of upper airway obstruction during sleep in children with Class II malocclusion is not known. Pirilä-Parkkinen et al. (1999) showed that the use of headgear treatment might increase the presence of upper airway obstruction. However, the difference with and without the treatment device was small. Morever, the clinical significance of the difference has been questioned, especially as the presence of the partial upper airway obstruction was not reliably estimated (Halbower et al. 2007). In another study, the use of headgear was noted to induce some reduction in the sagittal dimension of the upper airways in adults during N1-2 sleep (Hiyama et al. 2001). However, in the long run, the maxillary expansion, which is induced by the headgear treatment, if used with an enlarged inner bow, is expected to reduce the upper airway obstruction during sleep (Fenderson et al. 2004, Cistulli et al. 1998).

4.5 Consequences of untreated Class II malocclusion

Esthetics. Class II malocclusion has a large influence on the facial appearance. Shaw et al. (1985) studied the influence of malocclusion on the facial appearance based on the opinions of a large cohort of young adults. A normal incisor relationship gained the most favorable ratings and was associated with perceived friendliness, social class, popularity, and intelligence. However, the prominent incisor condition was rated highest for compliance and honesty. When a similar estimation was made in children by other children of the same age or adults, the children with a normal dental appearance were judged to be better looking, more desirable as friends, more intelligent, and less likely to behave aggressively (Shaw 1981). Schoolchildren estimated that teasing because of dentition features was more unpleasant than teasing because of various other features (Shaw et al. 1980). Dann et al. (1995) observed that children with Class II malocclusion at the age of 7 to 15 years did not generally have a low self-concept. Accordingly, the self-concept was not improved with a 15-month orthodontic intervention. In a recent, large study by de Paula et al. (2009), a broad range of adolescents' self-perceived impacts of dental esthetics is influenced by severity of malocclusion, oral health-related quality of life, and body satisfaction. It is worth noting that, in general, a small degree of maxillary and lip protrusion and dominance was considered attractive in women (Bisson and Grobbelaar 2004, Sarver 2001, Shaw et al. 1985).

Root resorption. Brin et al. (2003) observed less external apical root resorption with early- than with late-onset treatment of Class II malocclusion. This would appear to be the only report addressing such an association.

Temporomandibular joint. The association of temporomandibular joint (TMJ) complications with Class II malocclusion is controversial. The American Academy of Pediatric Dentistry stated in 1990 that there is no evidence supporting the relationship between malocclusion and complications of the temporomandibular joint. Furthermore, orthodontic treatment does not seem to prevent the development of TMJ problems. Helm and Petersen (1989) found no association between the most severe and persistent functional disorders and any particular malocclusion in a large longitudinal study. Several studies present contrasting evidence (Henrikson and Nilner 2003, Henrikson et al. 2000, Jansson 1981, Ricketts 1966, Stack and Funt 1977). Henrikson and Nilner (2003) observed more TJM problems in girls with Class II malocclusion than in controls. In a literature review, McNamara et al. (1995) concluded that a horizontal overjet of more that 6-7mm is generally related to TMJ problems.

In a large Finnish longitudinal follow-up study of a cohort of 384 schoolchildren, Jämsä (1991) observed that in a group of 34 children with orthodontic treatment, the elimination of remaining dental interferences by grinding after orthodontic treatment decreased pain symptoms of the stomatognathic musculature.

Dental trauma. In a large cohort of children, Forsberg and Tedestam (1993) found that abnormalities such as an overjet exceeding 4 mm, short upper lip, incompetent lips, and mouth breathing, increased the susceptibility to traumatic dental injury. The average overjet in children with enamel fractures was 4.3 mm. In more severe injuries, (dentine fracture, pulp lesion, root fracture or exarticulation), the mean overjet was significantly greater, 5.0 mm. The most common causes of injury were 'falls and blows', which were recorded as etiological factors in 69.9% of the boys and in 86.7% of the girls. Some kind of tooth injury has been stated to occur in every third child with Class II malocclusion (Forsberg and Tedestam 1993). Mohlin and Kurol (2003) reported that early correction of the large overjet, during the primary or mixed dentition period, might reduce the risk of traumatic injuries.

4.6 Prevalence of Class II division 1 malocclusion

There are several studies on the prevalence of Class II malocclusion in Caucasian populations. A summary of these studies is presented in Tables 6 and 7. The definition of Class II malocclusion varies between the studies or the criteria has not been mentioned exactly. In the deciduous dentition, a distal step relationship of the second deciduous molars corresponds to Class II occlusion in mixed and permanent dentitions. Class II division 1 malocclusion and dental crowding are the two most common indications for orthodontic treatment in Finland (Hannuksela 1977, Heikinheimo et al. 1987, Keski-Nisula et al. 2003, Väkiparta et al. 2005).

4.7 Correction of Class II division 1 malocclusion

The first treatment forms of Class II malocclusion included teeth extractions and the use of different anchorage devices (Kloehn 1947, Oppenheim 1936). During the 40's and 50's, functional jaw orthopedic devices were used in Europe, whereas fixed and extraoral force appliances were more common in the United States (Proffit 1993). Many treatment approaches are currently available for alteration of the occlusal relationships of Class II division 1 malocclusion. These include the use of functional (activators, occlusal guide appliances, Herbst appliance and Jasper Jumper), extraoral (headgear) and/or fixed appliances (e.g. edgewise appliance with intermaxillary elastic bands) (Proffit et al. 1993, Stucki and Ingervall 1998). These treatments may be carried out with or without teeth extractions.

There are two main treatment approaches in the correction of Class II malocclusions during the growing period: 1) intention to affect the teeth alignment of dental arches and to produce only dentoalveolar changes, or 2) intention to affect skeletal structures (McNamara 1981a). In the first approach the maxillary dentition is moved posteriorly and the mandibular dentition anteriorly. The second approach is based on the assumption that the skeletal relationships of the maxilla and the mandible can be affected during the growing period (McNamara 1981a). The principle of these methods is to prevent the forward and downward growth of the maxilla, and to stimulate the mandibular forward growth without or with only minor changes in the teeth on the alveolar arches (King et al. 1990).

The existence of different treatment approaches is due to the controversy over the nature and causes of Class II malocclusion. The apparent heterogeneity of Class II division 1 malocclusion has also probably increased the methodological diversity. To a certain extent, when expert clinicians use the method of their choice conscientiously, they can usually produce good correction of Class II malocclusion (Ghafari et al. 1998, Haralabakis et al. 2003).

Table 6. Prevalence of malocclusions in Caucasian populations, divided into Angle Classes (Emrich et al. 1965, Hannuksela 1977, Haralabakis 1957, Heikinheimo 1989, Helm 1968, Infante 1975, Johannsdottir et al. 1997, Kerosuo et al. 1991, Keski-Nisula et al. 2003, Korkhaus 1928, Massler and Frankel 1951, Myllärniemi 1970, Telle 1951, Trottman and Elsbach 1996, Tschill et al. 1997).

						Angle Classes of Malocclusions				
						I	II			III
				Age	Dentition		Total	Div1	Div2	
Study	Year	Nation	N	(y)	(D/M/P)	(%)	(%)	(%)	(%)	(%)
Finland										
Myllärniemi	1970	Finland	322	1-8[a]	D	13.6	5.9	4.3	1.6	
			756	4-14[b]	M	28.3	9.2	6.8	2.4	0.1
			453	8-19[c]	P	34.8	21.8	17.0	4.8	0.4
Hannuksela	1977	Finland	1200	9.6[d]	M		15.0			0.8
Heikinheimo	1989	Finland	181	5				0.6		
			200	7				3.5	3.0	
			176	10				10.8	3.4	
			195	12				13.3	1.5	
			190	15				7.9	2.1	0.5
Kerosuo et al.	1991	Finland	m208	13-18			19			2
			f250	12-18			9			2
Keski-Nisula et al.	2003	Finland	489	5.1[e]	M		33.1			
Other Countries										
Korkhaus	1928	Germany	643	6			16			6
			568	14			25			1
Telle	1951	Norway	2349	7-8	M	30.1	21.3			7.3
Massler & Frankel	1951	US	2758	14-18	P	50.1	19.4	16.7	2.7	9.4
Haralabakis	1957	Creek	592	19-30		36.3	23.1			2.5
Emrich et al.	1965	US	10133	6-8	D,M	18	11			1
			13475	12-14	P	30	15			1
Helm	1968	Denmark	m565	9-18	P		23.2			4.1
			f675	9-18	P		25.8			4.5
Infante	1975	US	268	2-3	D		24.3			0
			412	4-5	D		15.8			1.7
Trottman & Elsbach	1996	US	139	2-5	D		14			8
Johannsdottir et al.	1997	Iceland	396	m6	D,M		27			6
				f6	D,M		31			5
Tschill et al.	1997	France	789	4-6	D		26			

D = deciduous dentition; M = mixed dentition; P = permanent dentition; m = male; f = female

[a] In the deciduous dentition group one child was 7 and one 8 years old.

[b] In the mixed dentition group one was adolescent 18 years old.

[c] In the permanent dentition group two children were 8 and four 9 years old.

[d] The age of children was 9.6 years ± 5 months.

[e]Mean age of the children was 5.1years, range 4.0-7.8 years.

Table 7. Distribution of malocclusions in orthodontic populations (Angle 1899, Bradhorst 1946, Haralabakis 1957, Kerosuo et al. 1991, Willems et al. 2001).

						Angle Classes of Malocclusions				
						I	II			III
				Age	Dentition		Total	Div1	Div2	
Study	Year	Nation	N	(y)	(D/M/P)	(%)	(%)	(%)	(%)	(%)
Angle	1899	US	1000			69.2	26.6	12.4	14.2	4.2
Brandhorst[a]	1946	US	5288	9-10		77.2	19.1			3.3
Haralabakis	1957	Creek	367	19-30	P	58.5	37.3			4
Kerosuo et al.	1991	Finland	m205	5-18	D/M/P	77	22			1
			f242	5-18	D/M/P	84	15			1
Willems et al.	2001	Belgium	1477	6-60	D/M/P	31	63	52	11	6

D = deciduous dentition; M = mixed dentition; P = permanent dentition; m = male; f = female
[a]Brandhorst, the data sample was collected in 1932.

Headgear treatment and inhibition of the maxillary forward growth is considered favorable in Class II correction, if the maxilla is protrusive. (Cook et al. 1994, Kloehn 1947, Lima Filho et al. 2003b, Ricketts 1960). However, if the mandible is retrusive, functional devices have been suggested to have a more favorable effect (Bishara and Ziaja 1989, Chen et al. 2002). Whether or not the growth of the mandible may truly be stimulated by these functional devices is controversial (Chen et al. 2002). It has been suggested that the correction achieved by the use of functional appliances is primarily due to dentoalveolar changes (Björk 1951, Harvold and Vargervik 1971, Meach 1966, Wieslander and Lagerström 1979). A combination of different approaches is used. However, the fixed appliances are rarely used together with the headgear in the early treatment of Class II division 1 malocclusions (King et al. 1990) but may be considered in adolescent patients (Dewel 1968). In Finland, the headgear was reported to be the most commonly used appliance in the correction of Class II malocclusion (Pietilä et al. 2004).

4.7.1 Class II correction by cervical traction

Kloehn reported favorable results with headgear treatment of Class II malocclusion already in 1947 (Kloehn 1947). He used a head cap for extra-oral pull occipital anchorage. Thereafter, Ricketts et al. (1979) recognized that a downward pull is needed to enhance the orthopedic effect, and ultimately the cervical traction became the mainstay of the treatment.

The principle of the headgear. The principle of the headgear treatment is to apply a pulling force to the maxillary first molars in order to restrict the forward growth of the maxilla. The principle of an expansive headgear treatment is to combine the effects of the forward growth inhibition and the maxillary dental arch expansion. This is a way to expand the narrow maxillary arch (especially at the canine level), to alleviate dental crowding, and to normalize the forward growth of the mandible (Bench et al. 1978, Ricketts et al. 1979). It has been shown that cervical forces in excess of 450g are needed to obtain skeletal effects (Armstrong 1971, Graber 1969, Haas 1970, Klein 1957, Moore 1959, Poulton 1959, Ricketts 1960, Sandusky 1965, Wieslander 1963). The rationale for using a long outer bow is to prevent distal tipping and extrusion of the first molars (Greenspan 1970, Kuhn 1968). In correction of Class II malocclusion, the goal is to achieve a Class I molar relationship. Ricketts has suggested that, in fact, a small overcorrection may be preferable to obtain good and stable long-term results (Ricketts 1966, 1989a).

The impact of cervical headgear therapy on Class II malocclusion has been extensively studied for the last 60 years with greatly varying results. The variance was attributed to differences: 1) in the Class II malocclusions, and 2) in the headgear type and use (Bowden 1978a, 1978b, Lima Filho et al. 2003b, 2003c, Mäntysaari et al. 2004, Pirttiniemi et al. 2005, Tulloch et al. 1990, Tulloch et al. 1997a, Tulloch et al. 1998, Tulloch et al. 1997b, 2004, Tuncay and Tulloch 1992). Therefore, when comparing the treatment results, it is essential to recognize what kind of headgear has been used and how, and especially, whether other appliances have been used simultaneously.

Direction and strength of the force. With the headgear, the direction and the amount of traction force can vary considerably. High-pull, straight-pull, occipital-pull, and cervical-pull headgears and their combinations have been used (Bowden 1978a, 1978b, Firouz et al. 1992, Lima Filho et al. 2003b, 2003c, Mäntysaari et al. 2004, Pirttiniemi et al. 2005, Tulloch et al. 1990, Tulloch et al. 1997a, Tulloch et al. 1998, Tulloch et al. 1997b, 2004, Tuncay and Tulloch 1992). When light forces (150 – 200g) have been used for traction, only dentoalveolar changes and teeth movement have been observed (Bowden 1978a, 1978b, Reitan 1975). When stronger forces, exceeding 450g, have been applied, the tooth-movement threshold is presumably surpassed, teeth movement avoided, and teeth anchorage achieved (Bowden 1978a, 1978b, Graber 1969, Reitan 1975). With strong forces, skeletal effects on the protrusive maxilla, which are essential in the correction of Class II division 1 malocclusion, have been observed (Armstrong 1971, Graber 1969, Greenspan 1970, Haas 1970, Klein 1957, Kuhn 1968, Moore 1959, Poulton 1967, Ricketts 1960, Sandusky 1965, Wieslander 1963).

Headgear structure. A variety of inner and outer bows has been employed. The inner bow has been used with or without expansion, and kept either in or out of contact with the upper incisors (Bench et al. 1978, Ricketts et al. 1979). Bayonets have been used to stabilize the contact between the inner bow and the buccal tubes. Bayonet loops have been along either the vertical or the horizontal plane. In addition, different outer bow lengths and angles relative to the inner bow, have been used (Bowden 1978a, 1978b). The outer bows have been bent upward with the intention to prevent the distal tipping and overeruption of the molars (Greenspan 1970, Kuhn 1968).

The use of headgear. In many studies, headgear therapy has not been used alone, but along with fixed or functional appliances (Haralabakis et al. 2003, Weiland et al. 1997), and with or without tooth extractions (O'Reilly et al. 1993, Tulloch et al. 1990, Tuncay and Tulloch 1992). The age at onset of the treatment has been suggested to be a critical factor for the success of the treatment (King et al. 1990). Typically, the headgear is used at night-time. However, in some studies continuous use throughout the day and the night has been employed (Armstrong 1971, Brown 1978).

4.7.2 Results of correction of Class II malocclusion

The objective of the orthopedic treatment in Class II correction is to achieve an acceptable maxillo-mandibular relationship with balanced and harmonious facial features. Enhanced facial esthetics may improve the psychological well-being and self-image in children (de Paula et al. 2009).

It is obvious that these results may be achieved using many different treatment approaches. Tulloch et al. (Tulloch et al. 1990, Tuncay and Tulloch 1992) systematically reviewed the literature published between 1980 and 1987. They identified 50 studies in which the treatment of young patients with Class II malocclusion had been investigated. The function regulator and the activator with or without headgear were the two most often studied treatment approaches. The results in these studies were not consistent and no conclusions could be drawn regarding the treatment-specific effects. This was also true regarding the effects of headgear treatments. This attests to the concept mentioned above that the effects of headgear therapy cannot be generalized but depend on the headgear type and use, and that the heterogeneity of Class II malocclusion probably adds some variability to the results (Bishara et al. 1997, Carter 1987, McNamara 1981a, Moyers et al. 1980, Rosenblum 1995).

Lima Filho et al. (2003a) presented a case of a spontaneous correction of Class II malocclusion after rapid palatal expansion in the early mixed dentition. This case illustrates the treatment of Class II division 1 malocclusion with a transverse maxillary-mandibular skeletal discrepancy. After the expansion, the mandible seemed to be carried forward to its normal position, resulting in spontaneous correction of the malocclusion.

In children, headgear treatment was the most commonly used treatment of Class II malocclusion in Finland in 2000 (Pietilä et al. 2004). The treatment results, published mainly from Finland, Brazil, and the US, have been consistent when the headgear has been used as the only appliance and with the long, upward bent outer bow and the enlarged inner bow (Fenderson et al. 2004, Kangaspeska et al. 2001, Lima Filho et al. 2003b, c, Mäntysaari et al. 2004, Pirttiniemi et al. 2005). In general, the Class II first molar relationship has been successfully corrected to the Class I first molar relationship. During early headgear treatment, the eruption pattern of the upper canines becomes more vertical, and thus ectopic eruption is avoided (Silvola et al. 2009). The treatment results have been shown to be stable if retention devices are used (Fenderson et al. 2004, Lima Filho et al. 2003b).

4.7.3 Timing of correction

There are different opinions on the timing of the treatment of Class II malocclusion: early treatment or treatment during adolescence. The early treatment generally refers to a starting age of 8-11 years, before puberty. The early treatment is frequently followed by a second treatment phase to put the finishing touches to the occlusion with fixed appliances. The second approach in treatment timing targets the treatment to the highest growth at puberty, and the entire correction is accomplished in adolescence (Ghafari 1997, King et al. 1990, Pirttiniemi et al. 2005).

The principle of the early treatment is to utilize the great growth potential allowing relatively easy manipulation of the skeletal structures (Ghafari 1997, Gianelly and Valentini 1976, Graber 1969, King et al. 1990, Wieslander 1975). It is also thought that early onset allows the eruption of the permanent teeth into their natural position (Silvola et al. 2009). This should reduce the need for extractions and orthognathic surgery, and the risk of adverse iatrogenic effects, as well as create more stable treatment results (Antonini et al. 2005, Bishara 1998b, Dugoni 1998, Hamilton 1998, Reitan 1954) The other advantage of the early treatment is better compliance than with teenagers (King et al. 1990). However, there are others who have strongly questioned the effectiveness and the benefits of the early start of the treatment (Bowman 1998, Chate 1994, Gianelly 1994, 1995, Nelson 1997). Faltin et al. (2003) found that the response was more favorable and the results more stable if the correction of Class II malocclusion with the Bionator function appliance was performed during the peak growth period at puberty.

The best time for the onset of Class II correction has been investigated in only a few randomized studies. Tulloch et al. (1997b) suggested that nine years would be the optimum age for the onset of treatment in order to achieve the best correction of skeletal abnormalities. In randomized trials (Ghafari et al. 1998, Tulloch et al. 1998), there have been no significant differences in the outcome of Class II correction whether the treatment has been started in mid or in late childhood (Ghafari et al. 1998).

Finnish specialist orthodontists, working in the public health care sector, most often recommended the first assessment of occlusion before seven years of age. The late mixed dentition stage was considered as the best time for the onset of treatment in severe Class II malocclusions (Pietilä et al. 2008).

The timing of the treatment obviously also depends on when of the patient is referred for treatment. In Finland, the public health care system provides the possibility to follow up the development and the maturation of occlusion, and thus the treatment may usually be started at any time during the growth period of children (Keski-Nisula et al. 2003).

4.7.4 Cooperation

Cooperation by the patient is imperative for the success of the early treatment with the headgear or the functional appliances. Berg (1979) observed inadequate cooperation in

9 % of children treated with the headgear, and in 32% of children treated with an activator. The cooperation became poorer with the prolongation of the treatment (Berg 1979). The cooperation has been reported to be best in young children before adolescence (Allan and Hodgson 1968, Kreit et al. 1968, Weiss and Eiser 1977) or not to correlate with age at all (Clemmer and Hayes 1979). Children who are successful at school have been noted to show the best cooperation (Burns 1970, Herren et al. 1965, Kreit et al. 1968). However, in one study (Amado et al. 2008), the personality traits alone were not indicative of cooperation during adolescence.

5. AIMS OF THE STUDY

The aim of this study was to evaluate the effects of the cervical headgear treatment in the correction of Class II malocclusion of school-aged children. The headgear was used with the cervical strong pulling force, the expanded inner bow, and the long, upward bent outer bow. The effects of the treatment on the teeth and the dental arches were analyzed using dental casts, whereas the other aspects of the treatment were extensively analyzed using lateral and posteroanterior cephalograms. The specific aims of the study were to determine:

1. How well does the correction succeed without using other appliances?

2. Does the treatment associate with side effects, such as distal tipping and extrusion of the first molars, or increased facial height due to down and backwards rotation of the mandible, as has been previously suggested?

3. What are the effects of the treatment on the teeth, the dental arches, the growth of the maxilla, the mandible, the facial skeletal and soft tissue profile, and on the upper airways?

6. SUBJECTS AND METHODS

6.1 Subjects

In this thesis, data is presented from a total of 65 schoolchildren, 36 boys and 29 girls (Table 10). Original studies (I-V) each included 40 children, 20 boys and 20 girls. The study population was the same between studies I and II and then between studies III and V. Study IV had the same study population as the latter two studies with the exception of two boys and one girl. These partial changes to the study populations were made, first to have subjects with posteroanterior (PA) cephalograms for the study III and then, to allow the analysis of all soft tissue profile points in study IV. In the first study population, only fifteen children were with PA cephalograms. Three children for study IV were randomly selected from the first study population without PA cephalograms.

Studied children were all referred for treatment at the Health Center of Forssa because of Class II division 1 malocclusion. The children were born between the years 1975 and 1985. Their treatment documents were available for the study with the permission of the Health Center of Forssa and the Ethics Review Committee of the Hospital for Children and Adolescents, Helsinki University Hospital. The first two studies (I-II) were retrospective, whereas the last three studies (III-V) also included prospectively followed children, studies III and V, 16 boys and 9 girls, and study IV, 14 boys and 8 girls.

The inclusion criteria for the study enrollment were: 1) Class II division 1 malocclusion with at least an end-to-end Class II molar relationship, 2) overjet of more than 2 mm, 3) protrusive maxilla indicated in cephalometric analysis by the A-point position in the front of the nasion-pogonion line, 4) presence of pretreatment and posttreatment plaster models, 5) lateral cephalograms taken before and after the treatment, and from forty children also taken pretreatment and posttreatment posteroanterior cephalograms, 6) age 6 to 12 years at the time of referral, 7) generally healthy without baseline systemic diseases, malformations of known syndromes, and 8) good or at least moderate cooperation.

6.2 Control cohorts

I was not able to collect my own control material at the Health Center of Forssa. Hence, the study findings were either compared to the findings in the pre-existing Finnish cohort (Haavikko 1970) or values presented in the literature (Athanasiou et al. 1992, Bhatia and Leighton 1993, Huggare et al. 1993, Moorrees 1959, Riolo et al. 1974). The six used control cohorts are presented in Table 8.

The Finnish control group was randomly selected from a large cross-sectional lateral cephalometric material (Haavikko 1970). This original material consisted of lateral cephalograms taken from 1162 children and adolescents, who were living in Helsinki, and were between the ages of 2 and 21 years at the time of imaging (Haavikko 1970).

The lateral cephalograms were taken in a cephalostat. The large cohort was collected in the years 1965-1968 at the Department of Pedodontics and Orthodontics of the Institute of Dentistry, University of Helsinki. The six-year-olds were from the Virkkula kindergarten, or patients treated at the Department of Pedodontics and Orthodontics. The children between the ages of 7 and 14 years were all pupils of the Kaisaniemi and Aleksis Kivi elementary schools. The study population represented an unselected, local child population. The number of children in each one-year age group ranged from 39 to 101 (Table 8). The control data were previously unpublished, and were based on analysis of the previously taken cephalograms. Two different control cohorts were selected from this large cohort (Haavikko 1970): 1) all randomly selected children were accepted, including 611 children (351 boys and 260 girls) aged 6 to 14 years (II, IV), 2) only 80 randomly selected children with normal occlusion (Class I molar relationship with normal overjet and overbite) were accepted, ten children (5 boys and 5 girls) in each age group (thesis, V).

In study I, dental arch widths were compared to the values of nine-year-old Finnish children presented by Huggare et al. (1993). These children were born in Helsinki between the years 1968 and 1970, and the dental casts were taken during the years 1977 - 1979. The children had participated in a survey of dental development and oral health (Nyström 1982). In study I, the calculated annual changes in the maxillary and mandibular intercanine and intermolar distances were compared to the longitudinal normal values presented by Moorrees (1959).

In study II, the cephalometric findings were compared with values of the Finnish control group (Haavikko 1970) (unselected) and, in addition, with values of the British cohort (Bhatia and Leighton 1993). Extrusion of the first molars was evaluated, comparing the values of the upper and lower first molars to the normal US values, presented by Riolo et al. (1974).

In study III, posteroanterior, cephalometric measurements were compared to the Austrian control values, presented by Athanasiou et al. (1992). This control population consisted of 588 schoolchildren (157 girls and 431 boys) aged between 6 and 15 years in the years 1974 and 1975.

All control cohorts were collected well before my study (Table 8). In the US, Moorrees´ (1959) control cohort study consisted of a longitudinal analysis of plaster casts from 184 North American children of European origin, collected before and after World War II. In the Finnish data, reported by Huggare et al (1993), the dental casts were taken during the years 1977 – 1979 (Nyström 1982). The cephalograms of the Finnish control group (Haavikko 1970) were taken between the years 1965 and 1968. The data reported by Bhatia and Leighton (1993) were collected between the years 1952 and 1993 and the US data reported by Riolo et al. (1974) between the years 1953 and 1974. In the Austrian control cohort study consisted of the posteroanterior cephalograms, collected between the years 1974 and 1975 (Athanasiou et al. 1992). (Discussion, Study limitations)

Table 8. Description of control materials used (Bhatia 1993, Haavikko 1970, Huggare et al. 1993, Moorrees 1959, Riolo 1974).

Control Group	Athana-siou**	Bhatia and Leighton *	Haavikko* 1970	Huggare	Haavikko 1970 Class I	Moorrees*	Riolo *
Year, published	1993	1993	2000, 2007	1993	2007	1959	1974
Year, collected	1974-1975	1952-1993	1965-1968	1977-1979	1965-1968	1930, 1940 ***	1953-1974
Country	Austria	UK	Finland	Finland	Finland	US	US
Studies	III	II	thesis, II, IV	I	thesis, V	I	II
Measures	D	A, D	A, D	D	A, D	D	D
Age	n	n (B/G)	n (B/G)	n (B/G)	n (B/G)	n (B/G)	n (B/G)
6-7	8	52/57	34/18		5/5	43/59	30/41
7-8	72	57/61	36/38		5/5	48/58	64/21
8-9	56	57/63	49/34		5/5	44/52	64/37
9-10	54	58/63	42/21	22/19	5/5	37/31	52/47
10-11	70	58/63	47/54		5/5	23/21	53/47
11-12	89	58/63	25/37		5/5	18/15	53/47
12-13	75	58/63	46/15		5/5	15/13	57/40
13-14	87	58/63	19/20		5/5	16/16	57/42
14-15	58	58/63	53/23			11/14	58/43

*average value, **together boys 431 (73%), girls 157 (27%), ***years were not mentioned exactly, A = angles, D = distances or linear measurements.

6.3 Methods

6.3.1 Cervical headgear treatment

A Kloehn-type cervical headgear was used to treat Class II division 1 malocclusion in all children. The essential features of the headgear are a large inner bow and a long outer bow. To prevent buccal and distal tipping of the first molar crowns, the molar tubes were placed as close to the gingival margin and the rotation center of the first molars as possible (Worms et al. 1973). The inner bow was engaged so that the distance between the bow and the anterior teeth was 3 mm; 4 mm horizontal bayonets were bent to the inner bow, in front of the molar tubes, to keep teeth out of contact with cheek or lip. The ends of the inner bow were bent inwards, to prevent the rotation of the first molars or, if needed, to rotate the first molars into their correct position. The inner bow of the headgear was expanded to 10 mm wider than the distance between the maxillary first molar tubes and made parallel to the occlusal plane. To prevent distal tipping of the first molar crowns and extrusion of the first molars over the amount of the normal eruption, the long rigid outer bow was bent 15º upward.

A force of 500 g per side was used for cervical traction. The force was measured with a force gauge. The expansion of the inner bow and the amount of force used were controlled at 6–8-week intervals. The patients were asked to wear the headgear 12 to 14 hours a day, in the evenings and at nights, and to keep a daily diary of their headgear wear. Cooperation was estimated according to the diary notes and the signs of use, including the tearing of the elastic band and the neck strap. The posttreatment results were analyzed at the time of the correction when the Class I molar relationship was achieved.

6.3.2 Dental cast analyses (I, II, III)

Hard stone casts were prepared at the onset and the end of the treatment. These casts were used for measuring dental arch dimensions, overjet and overbite. Landmarks and measures are shown in Figure 1. All measuring points were identifiable in each subject. For dental arch width measurements, measuring points recommended by Moorrees (1959) were used. However, somewhat different landmarks were used than Moorrees´: 1) to eliminate the error introduced by axial tipping of incisors, the most gingival interincisal lingual point was selected instead of Moorrees´ tangent to the labial surfaces of central incisors. 2) To evaluate more precisely any changes in the position of first molars, the most central point on the mesial surface of the first molars was selected, instead of Moorrees´ most dorsal point on the distal surfaces of the deciduous second molars or the second premolars. 3) To eliminate the effect of axial tipping of the first molars, the lingual grooves of the first molars at the gingival level were also used. All these measurements were taken with a sliding digital caliper (Digit-Cal SI®, Tesa®, Switzerland) by the author.

The overjet was measured with a ruler between the maxillary and mandibular central incisors as the perpendicular distance in the sagittal plane, from the labial incisal edge of the maxillary central incisor to the labial surface of the mandibular central incisor (Moorrees 1959). Overbite was quantified as the part of the crown height of the mandibular incisors which was overlapped by the maxillary incisors: open bite, end-to-end, normal (1/3 – 1/2 overlapped), or deep bite (> 2/3 overlapped) (Moorrees 1959). Crowding was estimated, according to existing lack of space in the upper and lower dental arches, as mild (lack of space: ≤ ½ tooth), moderate (lack of space: > ½ – < 1½ tooth) and severe (lack of space: ≥ 1½ tooth). Arch perimeter was not measured because of lack of control values.

The measured dental arch widths were related to the reference values of nine-year-old Finnish children by Huggare et al. (1993). The calculated annual changes in the maxillary and mandibular intercanine and intermolar distances were compared with the reference values presented in the publication (Moorrees 1959).

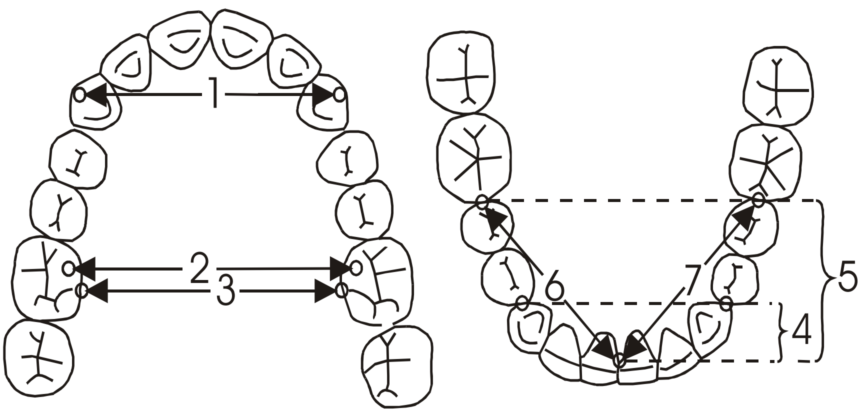

Figure 1. Used dental arch measurements: 1 = intercanine arch width; 2 = intermolar cuspal arch width; 3 = intermolar gingival arch width; 4 = anterior arch length; 5 = posterior arch length, 6 = right arch length, 7 = left arch length

6.3.3 Cephalometric analyses (II-V)

6.3.3.1 Posteroanterior cephalometry (III)

To analyze the effects of the cervical headgear therapy on the facial and dental widths (study III), (PA) cephalograms were taken before and after the treatment. The cephalograms were taken using a cephalostat (Cranex DC2, Tuusula, Finland). The distance between the ear rods and the film was kept fixed at 20 cm, and the distance between the anode and the film at 170 cm. The landmarks used in the analyses are presented in Figure 2. To estimate the correction factors of magnification for each landmark, a method described by Hsiao et al. (1997) was used: 1) Metal buttons of 1.5 mm in diameter were implanted in a dry human adult skull; 2) posteroanterior and lateral cephalograms were taken in the cephalostat, and 3) the cephalographic measures were compared to the original dry skull measurements to obtain correction factors for each landmark. In the description of the control population, Athanasiou et al. (1992) did not use any correction factor but compared all the distance measurements to the stable latero-orbital distance (lo-lo). Therefore, I calculated all my posteroanterior cephalometry measurements in three ways: 1) corrected only for magnification of the cephalograms taken in the cephalostat, 2) corrected by specific correction factor for each landmark, and 3) as a ratio to lo-lo measurement.

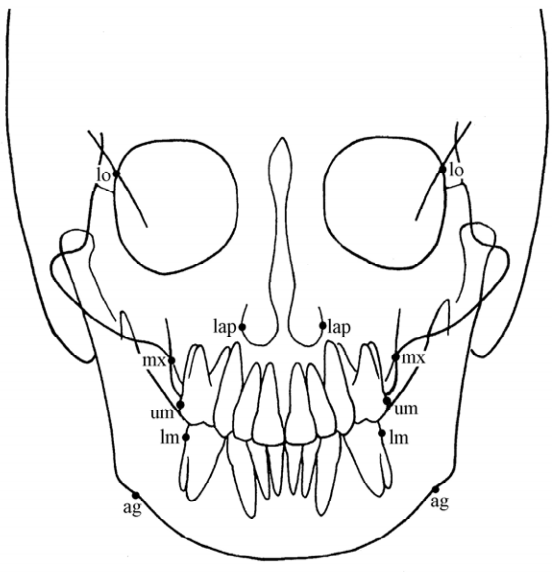

Figure 2. The skeletal and dental landmarks used in posteroanterior cephalometry. Refer to Table 9 for definitions.

6.3.3.2 Lateral cephalometry (II, IV, V)

Standardized lateral cephalometric radiographs were taken in a cephalostat (Cranex DC2, Tuusula, Finland) before and after the treatment. The lips were in a relaxed position and the teeth in the central occlusion. The magnification ratios were 170/150 (1.133) in the cephalostat used in the treated subjects and 164/155 (1.058) in the cephalostat used with the controls. Landmarks in the lateral cephalometric radiographs were traced and digitized by the author using special-purpose software (X-Metrics, BCD Co, Turku, Finland) together with a backlighted digitizer board. The bilateral structures were bisected. The linear measurements and angles were calculated by computer software designed for the study. The used landmarks are presented in Table 9 and Figure 3. Landmarks of the skeletal profiles were identified according to the criteria described by Bhatia and Leighton (1993), and landmarks of the soft tissue profile according to Legan and Burstone (1980). In the pharyngeal analysis, the pharynx was categorized into naso-, oro-, and hypopharynx, using the criteria by Pae et al. (1994). Lines parallel to the Frankfort horizontal plane were used in the determination of counterpart landmarks for ve, p, ph and eb on the posterior pharyngeal wall. The control values for studies II and V were digitized by another orthodontist.

Table 9. Cephalometric landmarks, angles and reference planes

Measure	Definition
Maxilla	
SNA	The angle sella (S) to nasion (N) to subspinale (A)
ANS-PNS	The length of the palatal plane from anterior nasal spine (ANS) to posterior nasal spine (PNS)
lo-lo	Latero-orbital distance
lap-lap	Internasal distance
mx-mx	Maxillary width
Mandible	
SNB	The angle sella (S) to nasion (N) to supramentale (B)
ANB	The angle subspinale (A) to nasion (N) to supramentale (B)
NS-MP	The angle nasion (N) to sella (S) to mandibular plane (MP). Mandibular plane is the line from mandibular base point (MBP) to menton (Me)
Co-Gn	Mandibular length. The length from the most posterior and superior point on the condylar head condylion (Co) to the most anterior and inferior point on the mandibular symphysis gnathion (Gn)
C3ai-HPT-Rgn	Sum of two distances: 1) the perpendicular distance between the most anterior and inferior point on the corpus of the third cervical vertebra (C3ai) and HPT. HPT is the vertical line from the most anterior and superior point of hyoid bone perpendicular to nasion (N) to sella (S) line with 7° upward correction (Legan and Burstone 1980) 2) the distance from most dorsal point of mandibular symphysis (retrognathion, Rgn) perpendicular to HPT
ag-ag	Mandibular width
Dental widths	
um-um	Upper first molar width
lm-lm	Lower first molar width
Facial Heights	
N-Me	The distance from nasion (N) to menton (Me), facial height
ANS-Me	The distance from anterior nasal spine (ANS) to menton (Me), lower facial height
Nasopharynx	The area outlined by a line between roof of the pharynx and posterior nasal spine (PNS), an extension of the palatal plane to the posterior pharyngeal wall, and the posterior pharyngeal wall.
S-PNS	The distance of sella (S) to posterior nasal spine (PNS)
ad1-PNS	The distance of ad1 to posterior nasal spine (PNS). Ad1 is the intersection point of posterior pharyngeal wall and the line from posterior nasal spine (PNS) to basion (Ba)
ad2-PNS	The distance of ad2 to posterior nasal spine (PNS). Ad2 is the intersection point of posterior pharyngeal wall and the line from the midpoint of the line from sella (S) to basion (Ba) to posterior nasal spine
Oropharynx	The area outlined by the inferior border of the nasopharynx, the posterior surface of the soft palate and tongue, a line parallel to the palatal plane trough the tip of epiglottis, and the posterior pharyngeal wall.
AA-PNS	The distance of the most anterior point of atlas vertebra (AA) to posterior nasal spine (PNS)
ve-pve	The distance of the closest point of soft palate to the posterior pharyngeal wall (velum palatinum, ve) to the horizontal counterpoint on the posterior pharyngeal wall (pve)
p-pp	The distance of the tip of soft palate (p) to horizontal counterpoint on posterior pharyngeal wall (pp)
pas	The distance of the intersectionpoints on anterior and posterior pharyngeal wall of the line from supramentale (B) to gonion (Go)
ph-pph	The distance of horizontal counterpoints on anterior and posterior pharyngeal wall in oropharynx at its narrowest area

Measure	Definition
Soft palate	
ANS-PNS-p	The angle anterior nasal spine (ANS) to posterior nasal spine (PNS) to palate point (p)
PNS-p	The distance of posterior nasal spine (PNS) to tip of soft palate (p)
sp1-sp2	The thickest cross section of the soft palate
Hypopharynx	The area outlined by the inferior border of the oropharynx, the posterior surface of the epiglottis, a line paralle to the palatal plane through the point C4ai, and the posterior pharyngeal wall.
eb-peb	The distance from vallecula of epiglottis (eb) to horizontal counterpoint on the posterior pharyngeal wall (peb)
Tongue	
length (tt-eb)	Tongue length. The distance from anterior point of tip of tongue (tt) to the base of epiglottis (eb)
height (th)	Tongue height. The perpendicular distance of superior point of tongue (th) bellow posterior nasal spine (PNS) to line from the tongue tip (tt) to the intersection point of tongue and mandibular border (tg)
Hyoid bone	
H-H’	The distance from the most anterior and superior point of hyoid bone (H) perpendicular to mandibular plane (MP)
H-C3ai	Hyoidale (H). The perpendicular distance from the most anterior and superior point of hyoid bone to perpendicular line from C3ai to HPT
Soft tissue profile	
g	Glabella. The most prominent point in the midsagittal plane of the forehead
n	Soft tissue nasion. The point of deepest concavity of the soft tissue contour of the root of the nose
pr	Pronasale. The most prominent or anterior point of the nose tip
cm	Columella. The most anterior point of the columella of the nose
sn	Subnasale. The point where the lower border of the nose meets the outer contour of the upper lip
a	Soft tissue a-point. The deepest point on the upper lip determined by an imaginary line joining subnasale with the labrale superius
ls	Labrale superius. A point located at the maximum convexity of the vermilion border most prominent in the midsagittal plane
stms	Stomion superius. The lowermost point on the vermilion of the upper lip
stmi	Stomion inferius. The uppermost point on the vermilion of the lower lip
li	Labrale inferius. The most prominent point on the vermilion border of the lower lip in the mid-sagittal plane
b	Mentolabial sulcus. The point of greatest concavity in the midline between the lower lip and chin
pg	Sort tissue pogonion. The most anterior point on soft tissue chin
Incisors	
UI	Maxillary central incisor
LI	Mandibular central incisor
UIE	Upper incisor incisal edge. The incisal tip of the maxillary central incisor
UIA	Upper incisor apex.The root tip of the maxillary central incisor
LIE	Lower incisor incisal edge. The incisal tip of the mandibular central incisor
LIA	Lower incisor apex. The root tip of the mandibular central incisor
LS	Horizontal counterpoint of labrale superius on the labial surface of the maxillary central incisor crown
LI	Horizontal counterpoint of labrale inferius on the labial surface of the mandibular central incisor crown

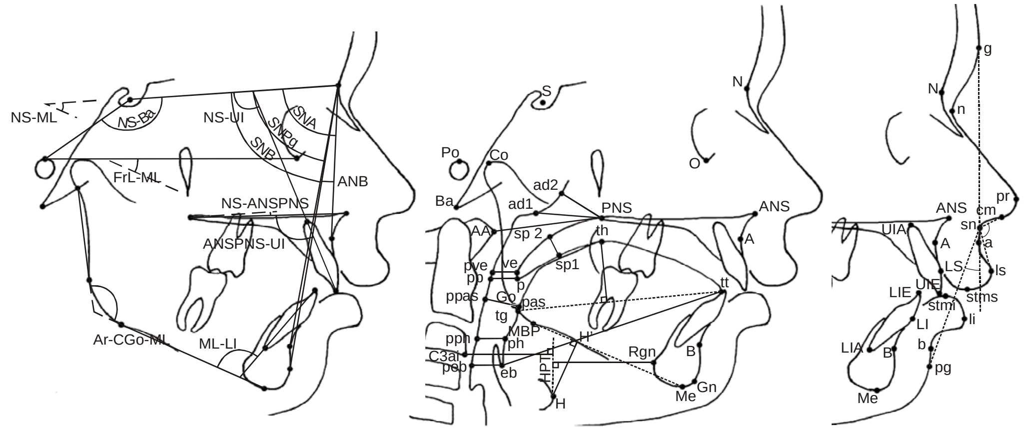

Figure 3. Used cephalometric landmarks and angles. Refer to Table 9 for definitions.

6.3.4 Statistical methods

Statistical analyses were calculated using SPSS 12.0.1 (SPSS, Inc, US). The results of the children with Class II division 1 malocclusion were compared to the calculated, age- and sex-matched average of the normal cohorts. The comparisons between individual values and the calculated control mean values were performed using paired t-tests. The paired t-test was also used to compare pre- and post-treatment measurements. A student t-test was used in the comparison of dental arch widths to the normal values in nine-year-old children presented by Huggare et al. (1993). Chi square test was used to test sex differences in cooperation.

For the definition of normal mean values in the analyzed 80 Finnish control Class I children (Haavikko 1970) (thesis, study V, Table 13, Figures 6, 7, and 9), a fourth order polynomial equation was fitted to the control group data using nonlinear curve fitting by GraphPad Prism 4.0 (GraphPad Software, Inc, US, Figures 6, 7, and 9). This calculated fitted mean was used to estimate the normal mean value for each particular age, and used in comparison to the study group.

Correlations between variables were calculated by linear regression analyses. P-values less than 0.05 were considered statistically significant. The values are presented in the form of mean ± standard deviation.

6.3.5 Method error

In study I, to estimate method error, serial pretreatment and posttreatment measurements were taken from plaster models of five randomly selected boys and five girls. In studies II, IV and V, serial pre- and posttreatment lateral cephalograms, and in study III, posteroanterior cephalograms of five randomly selected children were taken to assess measurement repeatabilitry. Method error was estimated using Dahlberg's formula (Dahlberg 1940):

$$ME = \sqrt{\frac{\sum d^2}{2n}}$$

where d is the difference between the first and second measured values, and n is the number of comparisons performed. Method error was estimated small in all of the measurements, the values are presented in Tables 11 to 15 together with the measurement results.

Existence of systematic method error was estimated by Forsberg's method (Forsberg 1976). The significance tests of the mean differences ($\bar{d}$) were calculated according to the formula:

$$t = \frac{\bar{d}}{\sqrt{\frac{\sum d^2}{n \cdot (n-1)}}}$$

If t-value was within the limits -2.07 < t < 2.07, the measurement was considered to be free of systematic error. None of the measurements presented with systematic error.

7. RESULTS

For the thesis, the results have been analyzed to cover all the 65 children studied whenever possible. The number of subjects included in the particular analysis will be indicated in parentheses. Class II division 1 malocclusion was corrected into Class I molar relationship in all 65 children treated. Table 10 shows the number of studied subjects, the average age at the onset of treatment of all 65 children, and of the children in each study, treatment times, co-operation, and the need for phase II treatment after the headgear therapy. Phase 2 treatment was needed in 34 out of 65 (52%) treated children, most often because of excess overjet or overbite: four children did not need further treatment, and 27 children continued to use the headgear every other or every third night as a retention appliance. At phase 2, 12 children needed fixed partial arches, and only 22 children needed full fixed appliances. Twenty-six out of 65 (40%) children with Class II malocclusion were observed to thrust the tongue during swallowing at clinical examination.

Table 10. Subjects and treatment characteristics

Study	All	I, II	III, V	IV
n	65	40	40	40
Boys	36	20	20	20
Girls	29	20	20	20
Age at Start (y)				
All subjects	9.3 (6.6-12.4)	9.3 (6.6-12.4)	9.1 (7.2-11.5)	9.1 (7.2-11.5)
Boys	9.5 (7.2-12.4)	9.8 (7.2-12.4)	9.2 (7.2-11.5)	9.3 (7.2-11.5)
Girls	9.0 (6.6-11.2)	8.9 (6.6-11.2)	9.0 (7.3-10.5)	9.0 (7.3-10.5)
Treatment time (y)				
All subjects	1.7 (0.3-3.1)	1.8 (0.8-3.1)	1.6 (0.3-3.1)	1.6 (0.3-3.1)
Boys	1.7 (0.9-3.1)	1.9 (0.9-3.1)	1.6 (0.9-3.1)	1.6 (0.9-3.1)
Girls	1.7 (0.3-2.9)	1.8 (0.8-3.0)	1.6 (0.3-2.9)	1.6 (0.3-2.9)
Cooperation (G/M/P)				
All subjects	50/15/0	30/10/0	33/7/0	32/8/0
Boys	26/10/0	13/7/0	16/4/0	15/5/0
Girls	24/5/0	17/3/0	17/3/0	17/3/0
Treatment visits (n)				
All subjects	14.4 (4-25)	15.2 (5-25)	13.9 (4-25)	13.9 (4-25)
Boys	14.3 (7-25)	15.3 (8-25)	13.8 (7-25)	14.0 (7-25)
Girls	14.4 (4-24)	15.1 (5-24)	14.0 (4-24)	13.8 (4-24)
Phase II Treatment				
All Subjects	34 (52%)	29 (73%)	18 (45%)	19 (48%)
Boys	19 (53%)	16 (80%)	9 (45%)	10 (50%)
Girls	15 (52%)	13 (65%)	9 (45%)	9 (45%)

G = good, M = moderate, P = poor cooperation

7.1 Dental arch measurements and dental cast analysis (I, II, III)

Changes in overjet, overbite and crowding during the headgear therapy (I, II, III; n = 65). In all subjects, the overjet decreased, on average, from 5.4 ± 2.1 mm (3 to 11 mm) to 3.6 ± 1.5 mm (1 to 8 mm) ($p < 0.0001$).

On average the overbite did not change significantly during the treatment ($p = 0.28$). Before the treatment, 42 children had a normal vertical overbite (1/3 – 1/2 overlapped), and this remained unchanged during the treatment. Of the remaining 23 children, 17 children had deep overbite (>2/3 overlapped). The bite become normal in seven of these children, in four the bite opened but did not reach normal limits, and in six, the overbite remained unchanged. Six children had an edge-to-edge bite before the treatment. In all but two of these children, a normal overbite was achieved with the treatment.

Crowding was analyzed only in study I. Eight of the 40 studied children had maxillary crowding before the treatment; two children had moderate and six had mild crowding. Nine children had mandibular crowding; one was severe, two moderate, and six mild. During the treatment, all children, except one boy, achieved good teeth alignment and enough space was gained for all teeth.

Changes in dental arch widths and lengths (I; n = 40, III widths; n = 40, thesis widths n = 65). Table 11 and Figure 4 show maxillary and mandibular intercanine and intermolar widths and lengths before and after the treatment. Intercanine and intermolar widths were compared to the US control values (children with Class I occlusion) presented by Moorrees (1959). Pretreatment maxillary intercanine width was 0.6 mm ($p = 0.03$) and mandibular intercanine width 1.4 mm ($p < 0.0001$) wider than in US controls. Maxillary and mandibular pretreatment intermolar widths did not differ from the control values. During the treatment, maxillary and mandibular intercanine and intermolar widths were widened more rapidly than in the US controls ($p < 0.0001$). Posttreatment maxillary intercanine distance was 4.7 mm and intermolar distance 4.8 mm wider than in the US controls ($p < 0.0001$). Posttreatment mandibular intercanine and intermolar distances were 3.0 mm and 2.1 mm wider than in the controls ($p < 0.0001$), respectively.

The results were also compared to the reference values of nine-year-old unselected Finnish children (Huggare et al. 1993). Before the treatment, maxillary intercanine and intermolar distances were significantly smaller ($p < 0.01$) and after the treatment larger than the reference values ($p < 0.001$). The mandibular intercanine distances did not differ from the reference values before the treatment, but were significantly greater than the Finnish control values after the treatment ($p < 0.01$). The mandibular intermolar distances were smaller than in the control children before treatment ($p < 0.001$), but were close to the controls after the treatment.

Table 11. Dental arch widths and lengths (mm). [a]n=65, otherwise n = 40. P values refer to comparison to control values (normal, Class I occlusion) by Moorrees (1959). For the dental arch lengths and the intermolar gingival widths were not normal control values.

	Pretreatment		Posttreatment				
	Mean	SD	Mean	SD	Change/ y	SD	ME
Maxilla							
Intercanine width[a]	31.7↑*	2.1	36.9↑****	2.0	3.1↑****	1.5	0.15
Intermolar cuspal width[a]	38.9	2.1	44.9↑****	3.0	3.4↑****	1.4	0.21
Intermolar gingival width	34.1	1.9	39.2	2.8	3.0	1.7	0.11
Anterior length	12.8	1.9	13.9	1.7	0.6	0.9	0.11
Posterior length	28.7	2.1	30.2	2.4	0.9	1.2	0.09
Right length	35.7	2.0	39.2	2.6	2.0	1.3	0.07
Left length	35.5	2.0	39.0	2.4	2.0	1.5	0.09
Mandible							
Intercanine width[a]	26.6↑****	2.1	28.1↑****	1.7	1.0↑****	1.3	0.12
Intermolar cuspal width[a]	33.5	2.0	36.4↑****	2.5	1.7↑****	1.0	0.12
Intermolar gingival width	32.0	1.6	34.2	2.1	1.3	0.7	0.09
Anterior length	7.3	1.6	8.0	1.4	0.5	0.8	0.13
Posterior length	24.2	1.7	23.6	1.9	-0.3	0.8	0.11
Right length	30.8	1.8	31.1	1.9	0.2	0.8	0.09
Left length	30.8	1.8	31.1	1.9	0.2	0.8	0.07

*p < 0.05; **p < 0.01; ***p < 0.001; ****p < 0.0001; an arrow after a number indicates if the value is longer (↑) or shorter (↓) than in the control, and whether it differs from the control values. ME = method error.

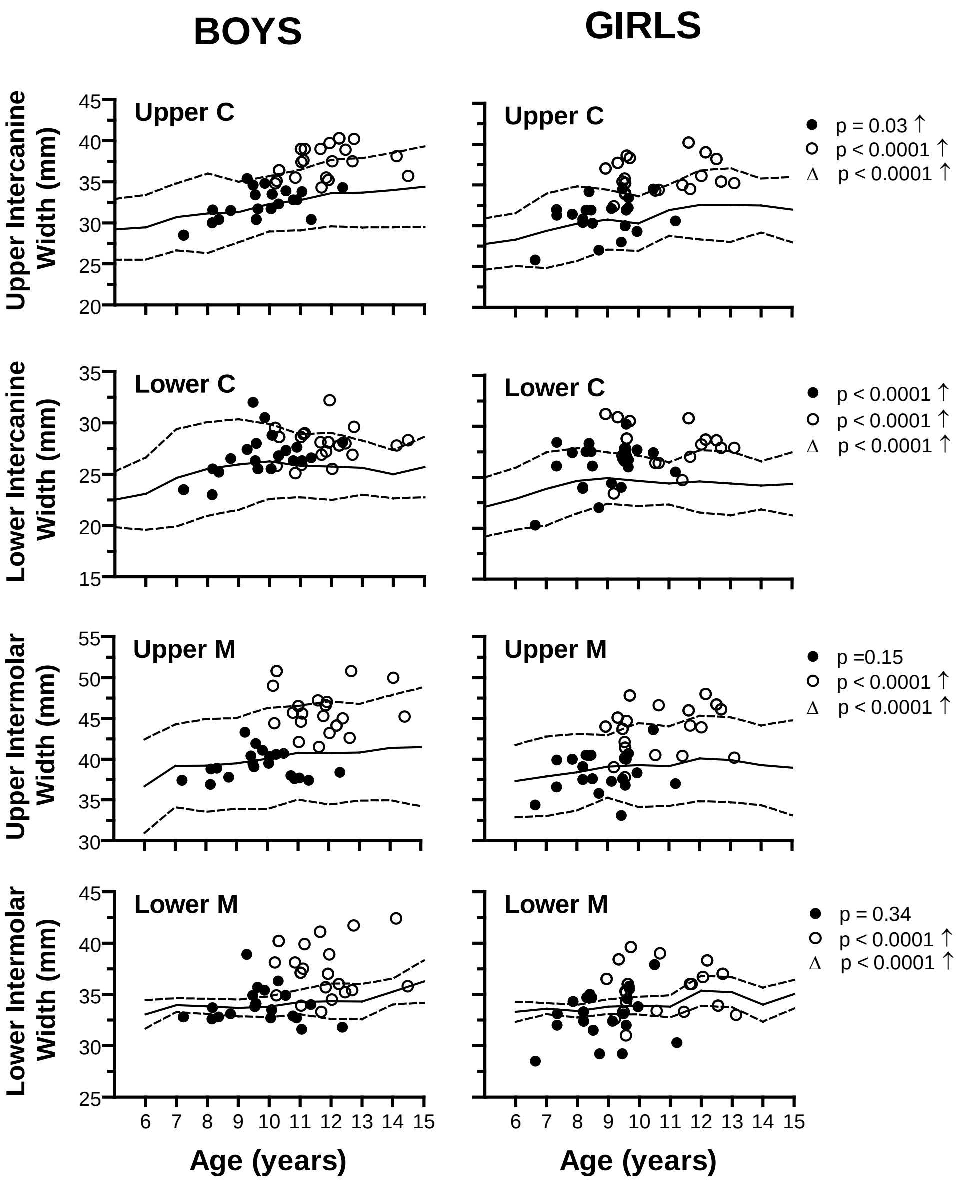

Figure 4. Dental arch widths in all treated children (n = 65), 36 boys and 29 girls. Results are presented against the normal values by Moorrees (1959). P-values refer to (●) pre- and (○) posttreatment differences and to differences in (Δ) growth. An arrow after the value indicates if the value is larger (↑) than in the controls and whether it differs from the control values.

7.2 Cephalometry (II, III, IV, V)

7.2.1 Posteroanterior cephalometry (III; n = 40)

Transversal measurements were compared to the control values of unselected school children with various occlusions, presented by Athanasiou et al. (1992). The changes in skeletal facial widths are shown in Table 12 and Figure 5. Measured transversal values of the posteroanterior cephalometry confirmed the results of the dental cast analysis. The maxillary and mandibular dental arches were widened by the treatment. The upper first molar width (um-um/lo-lo), the maxillary width (mx-mx/lo-lo), and the lower first molar width (lm-lm/lo-lo) increased more than in the controls ($p < 0.0001$). The mandibular width (ag-ag/lo-lo) remained unaffected. Maxillary widening was accompanied by widening of the nasal cavity. The lateronasal width (lap-lap/lo-lo) increased more than in the controls ($p < 0.005$).

The changes in the maxillary width (mx-mx, $r^2 = 0.28$, $p < 0.001$) and the nasal width (lap-lap, $r^2 = 0.30$, $p < 0.001$) correlated with the change in the intermolar distance (um-um). The change in the nasal width also correlated with the change in the (dental casts) intermolar distance ($r^2 = 0.19$, $p < 0.01$).

Table 12. Cephalometric posteroanterior measures (mm) (n = 40)

		Pretreatment		Posttreatment				
	Corr. factor	Mean	SD	Mean	SD	Change/y	SD	ME
Skeletal Widths								
mx-mx	0.919	59.1↑**	2.5	62.7↑***	3.0	1.6↑***	1.0	0.33
ag-ag	0.898	74.8↑*	3.4	78.1↑*	3.8	1.5	1.1	0.58
lap-lap	0.930	23.6↓***	2.4	25.8↓*	2.7	1.0↑**	0.8	0.19
lo-lo	0.927	84.0↓***	2.9	85.3↓***	3.4	0.6	0.9	0.10
Dental Widths								
um-um	0.919	54.9↑***	2.3	61.5↑***	3.0	3.2↑***	1.7	0.30
lm-lm	0.919	54.7↑***	2.0	56.3↑***	2.0	0.8↑***	0.8	0.17

*p < 0.05; **p < 0.01; ***p < 0.001; ****p < 0.0001; an arrow indicates if the value was longer (↑) or shorter (↓) than in the controls, and whether it differed from the control values (Athanasiou et al. 1992). All measurements were changed significantly ($p < 0.001$) when pre- and post-treatment values were compared to each other. All values were corrected with the presented correction factors (corr. factor) for the different magnifications. ME = method error.

Intermolar distance changes correlated significantly with PA cephalogram intermolar (um-um, $r^2 = 0.62$, $p < 0.001$) and maxillary width (mx-mx, $r^2 = 0.19$, $p < 0.01$) measurements. However, the cephalogram nasal width measurements correlated with gingival intermolar distances ($r^2 = 0.11$, $p < 0.05$), but not with maxillary cuspal intermolar distance ($r^2 = 0.06$, ns).

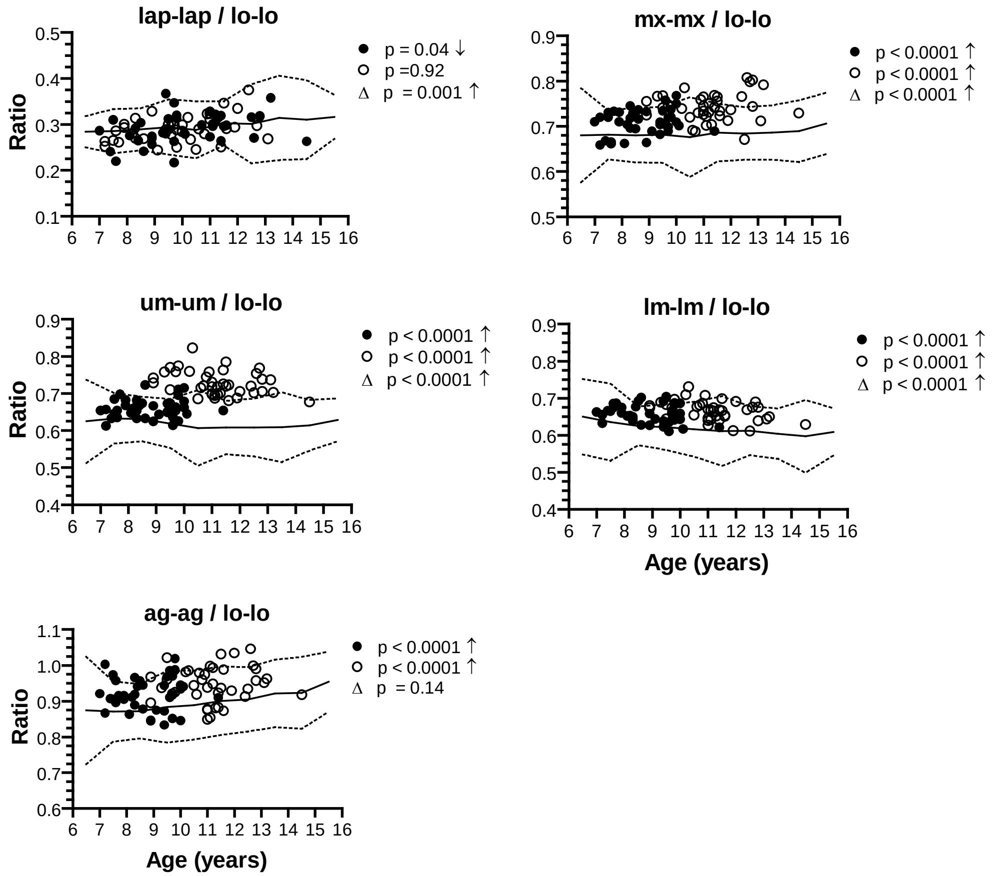

Figure 5. Cephalometric posteroaterior measurement values as a ratio to lo-lo measurement (n = 40). Results are presented against the normal values by Athanasiou et al. (1992). P-values refer to (●) pre- and (○) posttreatment differences and to differences in (Δ) growth. An arrow after a value indicates if the value is larger (↑) or smaller (↓) than in the controls, and whether it differs from the control values.

7.2.2 Lateral cephalometry (II, IV, V)

Changes in the Maxilla (II, IV, V; n= 40; thesis; n = 65). At the beginning of the treatment, the maxilla was in a protrusive position and the palatal plane inclined facially upward. The SNA angle was 2.2 ± 3.1° larger than in the Finnish controls ($p < 0.0001$) (Haavikko 1970) (unselected). The major effect of the cervical headgear treatment was seen at the A-point (Table 13, Figures 6 and 10). The forward growth of the maxillary A-point was restricted, while the rest of the facial structures grew forward at a normal rate (Figures 6 - 10). SNA decreased by 1.0 ± 0.7° per year more than in the Finnish controls ($p < 0.0001$) (Haavikko 1970) (unselected). At the end of the treatment the SNA angle did not differ between the groups ($p = 0.88$). Before the treatment, the palatal plane (NS – ANS-

PNS) was inclined anteriorly upward 1.5 ± 2.8° more than in the controls ($p < 0.0001$). During the treatment the palatal plane rotated anteriorly downward at a rate of 0.7 ± 0.6° per year ($p < 0.0001$) to a more horizontal position, to become positioned as in the controls ($p = 0.47$).The palatal plane (ANS-PNS) was 1.8 ± 6.3 mm longer in children with Class II malocclusion compared to the controls ($p = 0.02$). During the treatment the growth of the palatal plane was similar to that of controls ($p = 0.98$), and at the end of the treatment, its length did not differ between the groups ($p = 0.19$).

Table 13. Lateral cephalometric measures of maxilla, mandible and facial profile (n = 65)

	Pretreatment		Posttreatment				
	Mean	SD	Mean	SD	Change/y	SD	ME
Maxilla							
SNA (°)	82.5↑****	3.1	80.6	3.5	-0.9↓****	0.7	0.3
NS-ANSPNS (°)	5.1↓****	2.8	6.8	3.0	0.7↑****	0.6	0.6
ANS-PNS (mm)	47.3↑*	2.6	49.1	3.3	0.6	1.0	0.6
NS-UI (°)	104.9↑**	6.5	107.2↑****	6.6	1.2	3.4	1.0
ANSPNS-UI (°)	109.9	6.0	114.0↑****	6.0	1.9↑**	3.7	0.9
Mandible							
SNB (°)	77.6↑*	2.9	78.3	3.2	0.3	0.7	0.3
NS-MP (°)	31.8↓****	5.1	31.3↓**	5.5	-0.2	0.7	0.5
MP-LI (°)	97.8	7.4	97.1	7.3	-0.5	2.5	0.8
Facial convexity							
ANB (°)	4.8↑****	1.8	2.3	1.8	-1.1↓****	0.8	0.2
Facial Heights							
N-Me (mm)	100.8↑****	5.4	106.9↑****	5.7	2.5↑****	0.8	0.4
ANS-Me (mm)	58.4↑****	4.1	60.1↑****	4.6	0.6↓**	2.2	0.3

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$; an arrow indicates if the value is larger (↑) or smaller (↓) than in the controls, and whether it differs from the Finnish controls (Haavikko 1970) (unselected, boys = 362 and girls = 282). ME = method error.

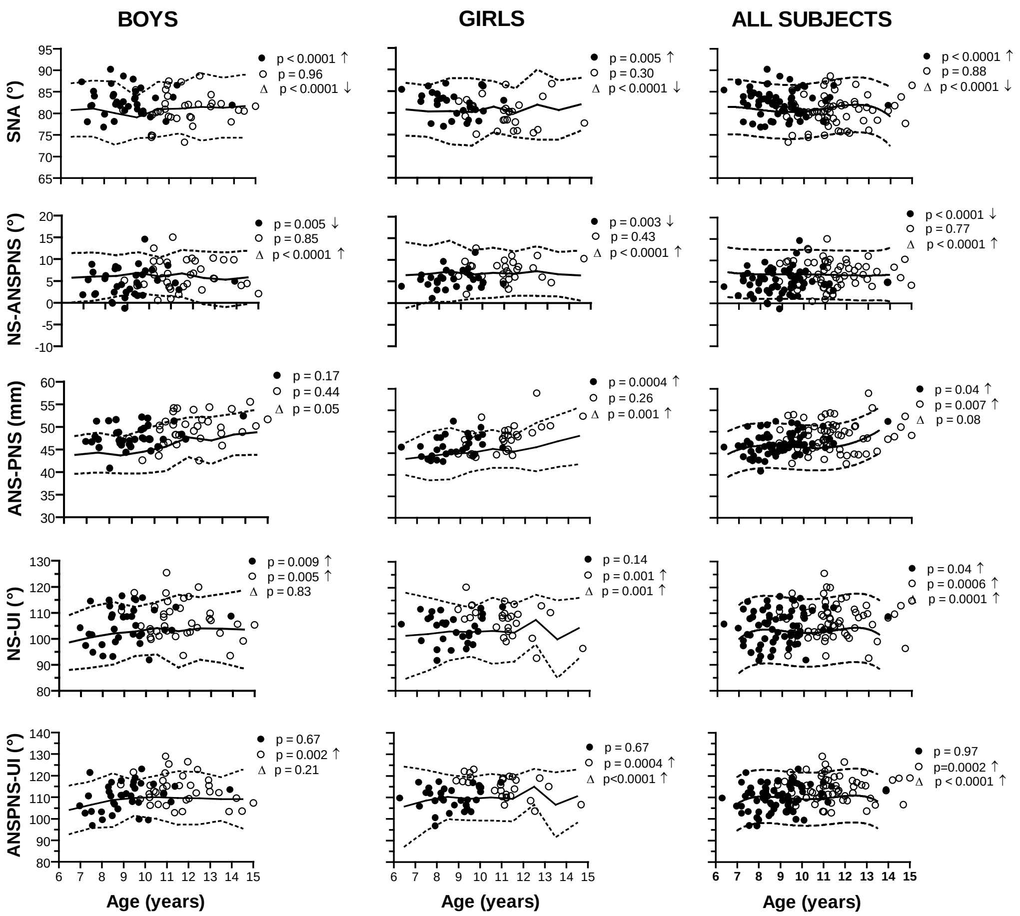

Figure 6. Individual changes in maxillary measurements (n = 65). Pre- and posttreatment values are presented against normal values, (Haavikko 1970) (two left panels: unselected, boys = 362 and girls = 282) and right panel in comparison to 80 Finnish Class I control children analyzed (Haavikko 1970). P-values refer to (●) pre- and (○) posttreatment differences and to differences in (Δ) growth. An arrow after a value indicates if the value is larger (↑) or smaller (↓) than in the control, and whether it differs from the control values.

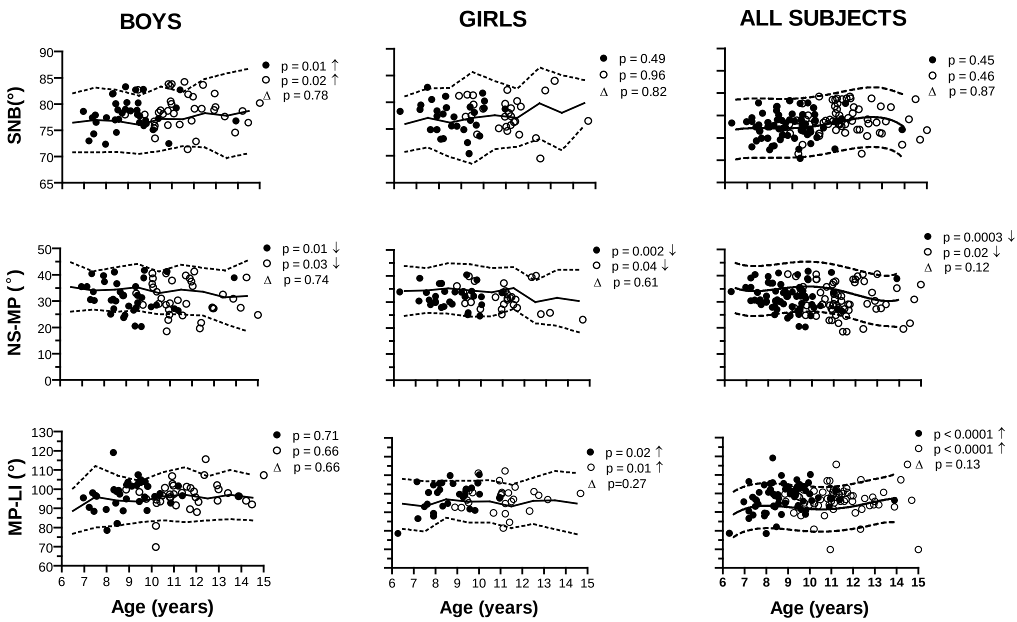

Figure 7. Individual changes in mandibular measurements (n = 65). Pre- and posttreatment values of boys and girls are presented against normal values (Haavikko 1970) (two left panels: unselected, boys = 362 and girls = 282; right panel: 80 Finnish Class I control children). P-values refer to (●) pre- and (○) posttreatment differences and to differences in (Δ) growth. An arrow after a value indicates if the value is larger (↑) or smaller (↓) than in the controls, and whether it differs from the control values.

Changes in the Mandible (II, IV, V; n = 40; thesis; n = 65). The headgear treatment did not have any major effect on the forward growth of the mandible. According to the SNB angle, the position of the mandible was slightly more advanced before the treatment, indicated by a 0.9 ± 3.0° (p = 0.02) larger SNB angle than in the Finnish controls (Haavikko 1970) (unselected, boys = 362 and girls = 282). The forward growth rate of the mandible was comparable between the two groups (p = 0.72). There was no significant difference in the SNB angle at the end of the treatment (p = 0.08). According to the mandibular plane angle NS-MP, the position of the mandible was 2.7 ± 5.2° more horizontal than in the controls (p < 0.0001) at the beginning, and 3.0º ± 7.8º at the end of the treatment (p = 0.003). The treatment did not significantly affect the NS-MP angle (p = 0.55). In the group of 40 patients (study II), Downs facial angle (FrL-NPg) was significantly smaller compared with the British control children (Bhatia 1993) both before and after the treatment (p < 0.0001), with a change similar to that in controls (Figure 8).

In study V (n=40), the length of the mandible (Co-Gn) did not differ from the Finnish Class I controls (Haavikko 1970) (selected) at the beginning of the treatment (p = 0.15). However, the length of the mandible increased 1.9 ± 3.5 mm per year more (p = 0.001) than the annual change in the control group (p = 0.001) to become 4.3 ± 7.1 mm longer (p = 0.0004) than in the controls at the end of the treatment.

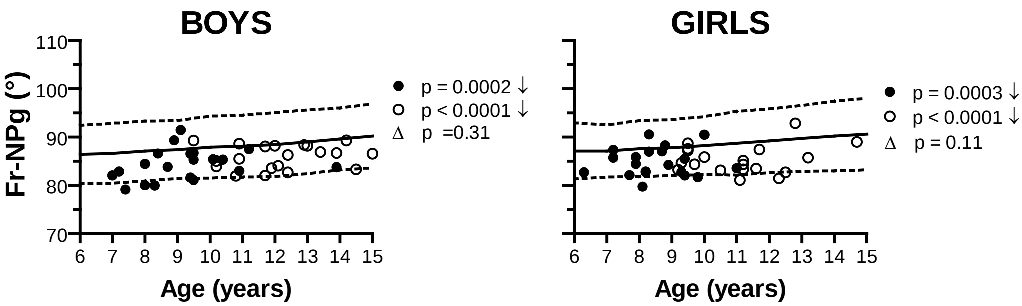

Figure 8. Downs' facial angle (FrL-NPg) in the patients of study II (n = 40). Pre- and posttreatment values are presented against normal British control values (Bhatia 1993). P-values refer to (●) pre- and (○) posttreatment differences, and to differences in (Δ) growth. An arrow after a value indicates if the value is smaller (↓) than in the controls, and whether it differs from the control values.

Incisors (II, IV, V; n = 65). In children with Class II malocclusion, the upper incisors were more anteriorly inclined (NS-UI) than in the controls. The treatment did not have a major effect on this inclination. The NS-UI angle was 2.5 ± 6.4° larger (p = 0.003) at the beginning of the treatment and 4.1 ± 7.2° larger (p < 0.0001) at the end of the treatment than in the Finnish controls (Haavikko 1970) (unselected, boys = 362 and girls = 282). The annual change in this angle did not differ between the groups (p = 0.06). The angle between the palatal plane and the upper incisors (ANSPNS-UI) did not differ from the controls before the treatment (p = 0.17), but increased simultaneously as the palatal plane was rotated anteriorly downward during the treatment. The ANSPNS-UI angle became 4.6 ± 7.1° larger (p < 0.0001) than in the controls. The annual change was 1.5 ± 3.6° per year more than in the controls (p = 0.001). Lower incisors (MP-LI) remained in a similar position to that of the controls throughout the treatment period.

Molar extrusion (II; n = 40). The treatment caused only minor, 0.3 ± 0.5 mm per year, extrusion of the upper first molars when compared to the Finnish controls (p = 0.0009) (Haavikko 1970) (unselected). The observed eruption was similar to that of the average of the US controls (p = 0.1) (Riolo et al. 1974).

Facial convexity (II, IV, V; n = 65). Inhibition of forward growth of the maxillary A-point, together with normal forward growth of other facial structures, decreased facial convexity (Table 13, Figures 6 and 7). However, this decrease was more evident on the skeletal than soft tissue profile. At the beginning of the treatment, the ANB angle was 1.3 ± 1.7° wider (p < 0.0001) in the children with Class II malocclusion than in the Finnish controls (Haavikko 1970) (unselected). During the treatment, the ANB angle decreased by 1.0 ± 0.8°per year more (p < 0.0001) than in the controls. The angle became similar (p

= 0.08) between the groups at the end of the treatment (Figure 9). Similarly, in a group of patients (study IV, n = 40), the facial convexity angle of the soft tissue profile (g-sn-pg) decreased by 0.7 ± 1.8° per year more (p = 0.02) in the treatment group compared with the controls. However, the soft tissue profile angle (g-sn-pg) did not differ significantly between the groups before (p = 0.07) or after (p = 0.49) the treatment.

Facial heights (II, IV, V; n = 65). The facial height (N-Me) was 2.3 ± 4.2 mm longer ($p < 0.0001$) at the beginning and 4.8 ± 5.3 mm longer ($p < 0.0001$) at the end of the treatment than in the Finnish controls (Haavikko 1970) (unselected). In addition, the growth rate of the facial height was 0.8 ± 0.8 mm per year more ($p < 0.0001$) than in the controls. Similarly, lower facial height (ANS-Me) was 4.2 ± 3.7 mm longer ($p < 0.0001$) at the beginning and 3.3 ± 5.0 mm longer ($p < 0.0001$) at the end of the treatment than in the controls. The lower facial height (ANS-Me) grew 0.2 ± 0.7 mm per year less ($p = 0.008$) than in the controls (Figure 9).

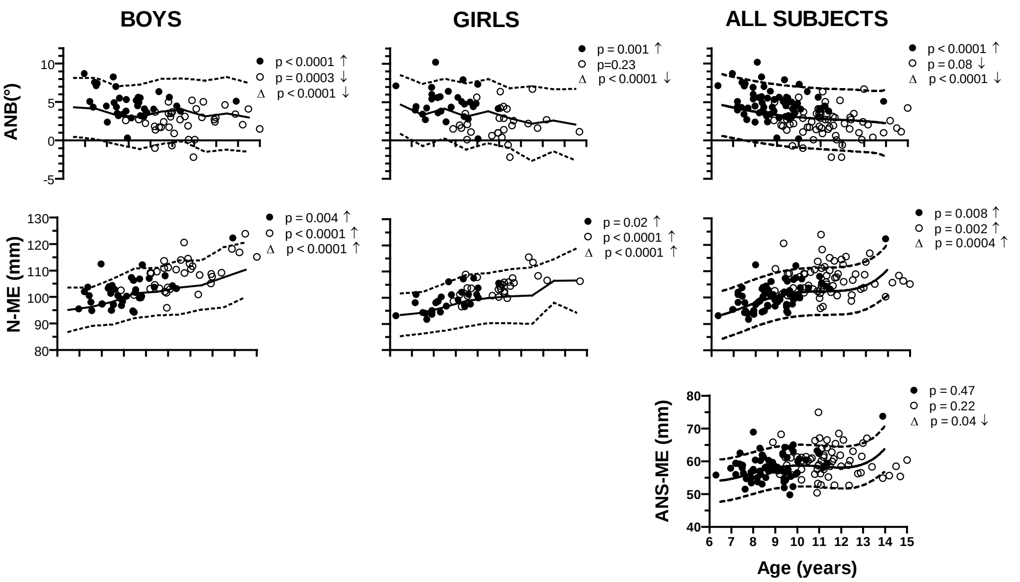

Figure 9. Individual changes in the facial convexity ANB (°), and facial heights N-ME and ANS-ME, (n = 65). Pre- and posttreatment values of boys and girls are presented against normal values (Haavikko 1970) (two left panels: unselected, boys = 362 and girls = 282; right panel: 80 Finnish Class I control children). P-values refer to (●) pre- and (○) posttreatment differences and to differences in (Δ) growth. An arrow after a value indicates if the value is larger (↑) or smaller (↓) than in the controls, and whether it differs from the control values.

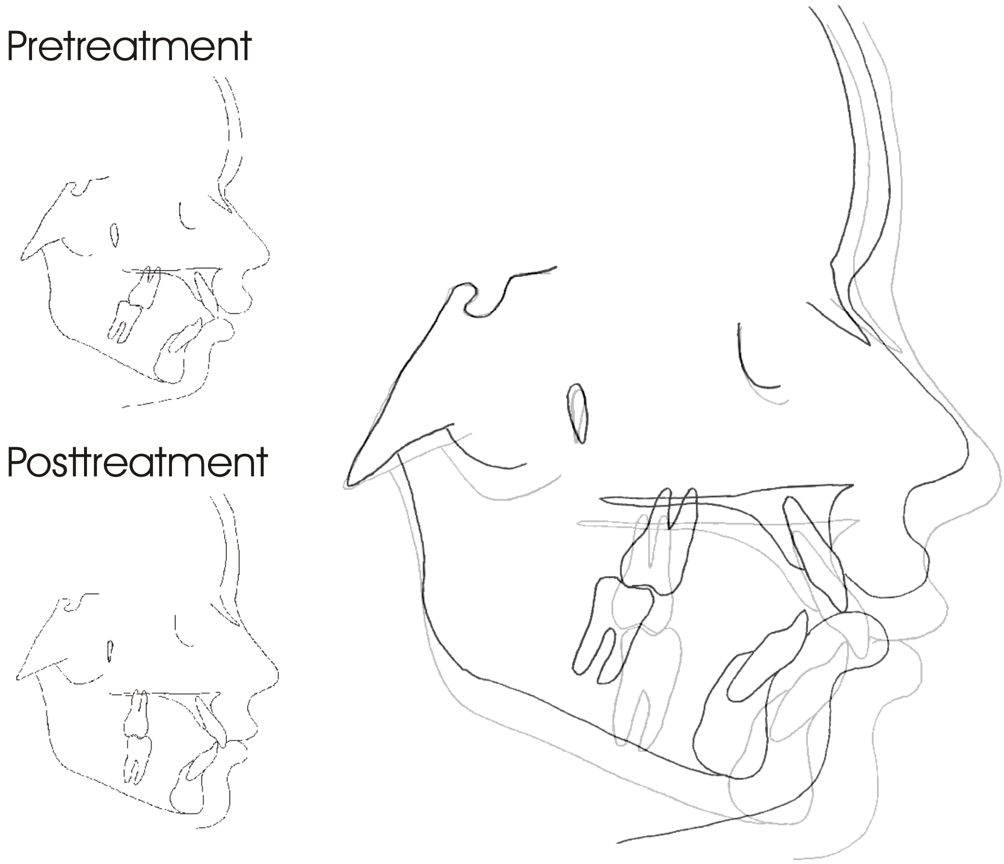

Figure 10. A typical example of change in facial profile during headgear therapy. The pre- and posttreatment cephalometric drawings of a girl. The cephalograms were taken at the ages of 8.0 and 11.0 years, respectively. In the superimposed picture, cranial base structures were used.

7.2.3 Soft tissue profile (IV; n = 40)

Lips (IV, n = 40). The children with Class II malocclusion had prominent and protruded lips (Table 14). The headgear treatment did not have a significant effect on lip thicknesses, even though upper lip protrusion was decreased. Before the treatment, upper lip thickness (ls-LS) was 1.8 ± 1.8 mm ($p < 0.0001$) longer than in the controls, and the lower lip thickness (li-LI) 1.7 ± 2.6 mm ($p = 0.0002$) longer. Measurements a-A 0.9 ± 1.7 mm ($p = 0.002$) and b-B 0.6 ± 1.2 mm ($p = 0.008$) were longer than in the controls (Haavikko 1970) (unselected). After the treatment, the upper lip thickness remained 1.9 ± 2.1 mm ($p < 0.0001$), lower lip thickness 1.5 ± 2.1 mm ($p < 0.0001$), a-A 1.5 ± 1.7 mm ($p < 0.0001$) and b-B 0.7 ± 1.5 mm ($p = 0.005$) longer than in the controls. Before the treatment, upper (ls – sn-pg) and lower (li – sn-pg) lips were protruded by 1.5 ± 1.6 mm ($p < 0.0001$) and 0.7 ± 2.0 mm ($p = 0.03$) compared with the controls. Upper lip protrusion (ls – sn-pg), was decreased by 0.6 ± 0.8 mm more ($p < 0.0001$) than in the controls. There were no differences in upper (ls – sn-pg) ($p = 0.88$) or lower (li – sn-pg) ($p = 0.25$) lip protrusion between the groups after the treatment. Before the treatment the nasolabial angle (cm-sn-ls) was 5.8 ± 9.8° ($p = 0.0006$) smaller in the treated children compared to the controls, but this difference disappeared during the treatment ($p = 0.74$).

Table 14. Cephalometric soft tissue profile measurements (n = 40)

	Pretreatment		Posttreatment				
	Mean	SD	Mean	SD	Change/y	SD	ME
Convexity							
g-sn-pg (°)	14.3	5.0	13.4	5.1	-0.5$^{\downarrow *}$	1.4	0.3
Lips							
cm-sn-ls (°)	103.9$^{\downarrow ***}$	9.5	105.6	8.6	0.6	3.4	2.0
a-A (mm)	12.9$^{\uparrow **}$	1.9	14.0$^{\uparrow ****}$	1.7	0.6	0.9	0.6
ls-LS (mm)	12.9$^{\uparrow ****}$	1.8	13.0$^{\uparrow ****}$	2.1	0.0	0.6	0.7
ls-sn-pg line (mm)	5.7$^{\uparrow ****}$	1.7	4.6	1.8	-0.5$^{\downarrow ****}$	0.6	0.3
stms-stmi (mm)	3.5	4.1	1.1$^{\downarrow ****}$	1.9	-1.3$^{\downarrow ***}$	2.3	0.2
li-LI (mm)	14.2$^{\uparrow ***}$	2.5	14.0$^{\uparrow ****}$	2.2	-0.1	0.8	0.4
li-sn-pg line (mm)	4.0$^{\uparrow *}$	2.0	3.9	1.8	0.0	0.6	0.3
b-li-pg line (mm)	4.2	1.4	4.5	1.5	0.1	0.5	0.2
b-B (mm)	9.6$^{\uparrow **}$	1.3	10.2$^{\uparrow **}$	1.5	0.3	0.7	0.2
Nose							
n-pr (mm)	36.1$^{\downarrow **}$	3.8	38.9	3.4	1.3	1.3	0.6
pr-sn (mm)	15.3	1.7	16.3	1.9	0.4	0.6	0.4

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ****$p < 0.0001$; an arrow after a number indicates if the value is longer (↑) or shorter (↓) than in the controls (Haavikko 1970) (unselected), and whether it differs from the controls. ME = method error.

The headgear treatment decreased the gap (stms-stmi) between the lips. The gap was similar between the groups ($p = 0.65$) before the treatment but was decreased in the treated children by 1.4 ± 2.5 mm per year more ($p = 0.0009$) than in the controls. After the treatment, the lips were even 2.4 ± 2.5 mm ($p < 0.0001$) closer to each other than in the controls.

Nose (IV, n = 40). The children with Class II malocclusions had 1.6 ± 3.6 mm ($p = 0.006$) shorter nose length (n-pr) than the controls before the treatment. After the treatment, this difference had disappeared ($p = 0.87$), although there was no significant difference in annual growth rate between the groups. Nose depth (pr-sn) was similar between the groups and was unaffected by the treatment ($p = 0.09$) (Table 14).

Table 15. Upper airway dimensions (n = 40)

	Pretreatment		Posttreatment				
	Mean	SD	Mean	SD	Change/y	SD	ME
Nasopharynx							
S-PNS (mm)	$43.0^{\uparrow****}$	2.9	$44.4^{\uparrow***}$	3.2	0.6	0.4	0.3
ad1-PNS (mm)	21.1	4.3	21.1	4.3	0.0	2.0	0.5
ad2-PNS (mm)	$16.2^{\uparrow*}$	3.5	$17.3^{\uparrow**}$	4.4	$0.6^{\uparrow*}$	1.5	0.7
Oropharynx							
AA-PNS (mm)	32.2	3.5	$31.0^{\downarrow*}$	2.6	-0.6	1.4	0.6
ve-pve (mm)	$8.1^{\downarrow****}$	2.2	9.1	2.4	$0.4^{\uparrow*}$	1.3	0.5
p-pp (mm)	$10.1^{\downarrow***}$	2.4	10.6	2.6	$0.2^{\uparrow*}$	1.6	0.3
pas (mm)	$11.0^{\downarrow***}$	3.1	$11.1^{\downarrow**}$	3.2	0.0	1.8	0.5
ph-pph (mm)	$9.7^{\downarrow***}$	2.6	9.9	3.7	0.1	2.1	0.3
Soft palate							
ANS-PNS-p (º)	$139.3^{\uparrow***}$	5.9	$131.6^{\downarrow***}$	5.9	$-3.6^{\downarrow****}$	2.5	2.4
PNS-p (mm)	28.1	3.0	28.4	2.6	0.1	1.3	0.8
sp1-sp2 (mm)	7.7	1.1	7.7	1.1	0.0	0.8	0.4
Hypopharynx							
eb-peb (mm)	$12.3^{\downarrow****}$	2.7	$13.1^{\downarrow****}$	3.2	0.2	2.0	0.4
Tongue							
length (tt-eb) (mm)	64.6	5.2	67.0	4.2	0.9	1.9	0.4
height (th) (mm)	$20.1^{\uparrow***}$	2.7	$22.2^{\uparrow****}$	3.3	$1.0^{\uparrow*}$	1.7	1.2
Hyoid bone							
H-H’ (mm)	$10.3^{\downarrow**}$	3.9	$9.9^{\downarrow****}$	3.9	$-0.4^{\downarrow*}$	2.2	0.3
H-C3ai vertical line (mm)	-0.4	5.3	-1.0	6.4	$-0.6^{\downarrow*}$	2.6	0.2

*p < 0.05; **p < 0.01; ***p < 0.001; ****p < 0.0001; an arrow indicates if the value is longer (↑) or shorter (↓) than in the 80 Finnish Class I controls (Haavikko 1970), and whether it differs from the controls. ME = method error.

7.2.4 Upper airway dimensions (V, n = 40)

Adenoids. Adenoids had been removed in 14 children prior to the headgear therapy during early childhood. There were no other significant differences in the upper airways measurements between the children with and without adenoidectomy except in the parameters, ad1-PNS and ad2-PNS distances. These measurements were longer before the treatment in the children who had undergone adenoidectomy ($p = 0.02$) and ad2-PNS remained longer ($p< 0.05$) than in the controls after the treatment. The SNA angle also decreased less during the treatment in the children whose adenoids had been removed ($p = 0.004$).

Nasopharynx (V, n = 40). The subjects in the treatment group had a similar or wider nasopharynx than the 80 Finnish Class I normal controls. This was not affected by the treatment (Table 15). The distance S-PNS was 2.0 ± 2.7 mm longer ($p < 0.0001$) pretreatment, and 1.9 ± 3.0 mm longer ($p = 0.0002$) posttreatment. In addition, ad2-PNS was longer ($p = 0.02$) than in the controls. However, this difference was observed only in those patients whose adenoids had been removed. The ad1-PNS distance was similar to that of the controls both pretreatment ($p = 0.50$) and posttreatment ($p = 0.15$).

Oro- and hypopharynx (V, n = 40). The treated children had narrower oro- and hypopharynx (AA-PNS ns; ve-pve 1.8 ± 2.2 mm, $p < 0.0001$; p-pp 1.8 ± 2.4 mm, $p < 0.0001$, pas 1.7 ± 3.2 mm, $p = 0.0004$; ph-pph 1.9 ± 2.8 mm, $p = 0.0002$; eb-peb 3.1 ± 2.7 mm, $p < 0.0001$) than the controls before the treatment (Table 15). The retropalatal area was widened by the treatment, whereas the rest of the oropharynx and hypopharynx remained narrower than in the controls. In the retropalatal area, ve-pve increased 0.6 ± 1.7 mm per year more ($p = 0.03$), and p-pp increased 0.6 ± 1.7 mm per year more ($p = 0.03$) than in the controls.

Tongue and hyoid bone position (V, n = 40). The length of the tongue (tt-eb) was similar to that of the controls and was unaffected by the treatment. Tongue height (th) was 1.8 ± 2.6 mm longer ($p = 0.0001$) before and 3.1 ± 3.2 mm longer ($p < 0.0001$) after the treatment in the treated children compared with the controls ($p = 0.0001$). The increase in tongue height (th) exceded by 0.7 ± 1.7 mm per year the changes observed in the control group ($p = 0.01$). Hyoid bone was 2.1 ± 4.5 mm closer ($p = 0.008$) to the mandible (H-H') in the treatment group before, and 4.1 ± 4.1 mm closer ($p < 0.0001$) after the treatment than in the controls. The H-H´distance became 0.4 ± 2.2 mm per year shorter during the treatment, while in the control group, the distance increased by 0.7 ± 0.9 mm per year ($p = 0.01$).

8. DISCUSSION

This study shows that Class II malocclusion may be successfully converted to a Class I molar relationship using the cervical headgear therapy as the only appliance during childhood. The treatment was successful in this respect in all 65 treated children. After the headgear treatment, a phase two treatment was needed in 52% of the children, most often because of excess overjet or overbite.

Essential features of the cervical headgear therapy were the use of an expanded, large inner bow, the use of a long outer bow, and the use of strong 500 g nuchal traction force. By expanding the inner bow, an expansive force was induced to the maxilla, and to the maxillary dental arch. The treatment widened the maxilla and the maxillary dental arch in parallel with the correction of the malocclusion. In the mandible, only the dental arch, not the major bony part, was widened spontaneously during the treatment. These results were established both by the dental cast and by the posteroanterior cephalometric analyses. The widening of the dental arches reduced crowding. I suggest that the widening is essential in the establishment of a proper treatment result by enabling the normal forward growth of the mandible. This is supported by the earlier negative treatment study results concerning the growth of the mandible. In these studies, the cervical headgear was used without expansion of the inner arch. In such cases, extrusion of the upper molars and posterior rotation of the mandible were found (Baumrind et al. 1983, Baumrind et al. 1981, Baumrind et al. 1978, Klein 1957, Melsen 1978, Poulton 1967). Before the treatment, the treated children had a 1.4 mm wider mandibular but only a 0.6 mm wider maxillary intercanine width than the US control children (Moorrees 1959). Therefore, I suggest that significant maxillary widening allowed forward movement of the mandible, and the correction of the malocclusion. The treatment did not affect the SNB angle, indicating that the mandible grew forward at a normal rate. In several studies, it has been concluded that one of the skeletal features of Class II malocclusion was mandibular retrognatism (McNamara 1981a, Rosenblum 1995). However, according to the analyses used in this study, the studied children with Class II malocclusion did not have mandibular retrognatism.

Prior to the treatment, the children with Class II malocclusion had protrusive maxilla. The most prominent treatment effect produced by the cervical traction was restricted forward growth of the maxillary dental arch. The SNA angle was markedly decreased and the maxillary A-point stayed on the same plane without any forward movement, while the rest of the facial profile grew forward at the same rate as in the controls. In addition, the maxillary anterior nasal spine grew forward at normal growth velocity, and the nose length increased even more than in the controls. The restriction of the forward growth of the maxillary dental arch led to a significant decrease in maxillary prognatism and decreased facial convexity. Headgear treatment also induced downward rotation of the palatal plane, but at the same time, the maxillary incisors became more facially inclined. Nevertheless, the net effect of the two changes was toward a favorable treatment effect. The nasolabial angle decreased, indicating some decrease in the upper lip protrusion.

At the onset of treatment, the soft tissue differences between the controls and children with Class II malocclusion were milder than the skeletal differences. Therefore, it seems that the soft tissues mask the underlying malocclusion and skeletal abnormalities. The children with Class II malocclusion had significantly narrower nasal width (lap-lap) than the Austrian control cohort (Athanasiou et al. 1992). The significant maxillary widening during Class II correction also widened the nasal width toward normal. Class II malocclusion was accompanied by a similar or wider nasopharyngeal space than in the controls, but narrower oro- and hypopharyngeal spaces. The retropalatal area was widened by the treatment, whereas the rest of the oropharynx and hypopharynx remained narrower than in the controls. The increased nasal width, together with the increased retropalatal area, observed during the treatment, should facilitate nasal breathing (Hershey et al. 1976, Warren et al. 1987).

8.1 Maxillary widening

The main reasons for the use of maxillary widening were to treat dental crowding and to obtain enough space for the mandible to grow forward despite the restricted forward growth of maxilla (Bench et al. 1978, da Silva Filho et al. 2008).

Most published observations indicate that children with Class II malocclusion have narrow maxilla (Baccetti et al. 1997, Tollaro et al. 1996, Varrela 1998). This narrowness is seen already at the deciduous dentition stage (Baccetti et al. 1997, Varrela 1998). However, the children with Class II malocclusion included in this study did not show maxillary or mandibular arch narrowness. Mandibular intercanine width was significantly wider than in the controls. The maxillary intercanine widths were much closer to the normal values of US children with Class I occlusion (Moorrees 1959). The treated children also had wider maxilla, mandible and molar widths than the Austrian school children with various occlusions (Athanasiou et al. 1992).

The headgear was used in this study with a widened inner bow. The inner arch of the headgear was made 10 mm wider than the intermolar distance. With inner arch expansion, the maxilla, and maxillary and mandibular dental arches were significantly widened. This widening was observed as increased intercanine and intermolar distances that were larger than in the US controls (Moorrees 1959). In addition, the increased maxillary width and increased intermolar distances of the upper and lower dental arches were larger than in the Austrian controls (Athanasiou et al. 1992). In dental cast analysis, to exclude possible changes in this width due to the change in axial inclination of the molars, the increase in intermolar width was measured both from the cusp tips and from the lingual grooves at the gingival level. A similar widening was observed in both of these measurements. Despite the widening of the mandibular dental arch, the growth of the mandibular major bony part width remained similar to that of controls.

The headgear treatment has been claimed to induce downward and backward rotation of the mandible and bite opening (Baumrind et al. 1983, Baumrind et al. 1981, Baumrind et al. 1978, Klein 1957, Melsen 1978, Poulton 1967). It has been suggested that these problems might be avoided if cervical traction is combined with dental arch widening (Bench et al. 1978, Cook et al. 1994, Mäntysaari et al. 2004, Pirttiniemi et al. 2005). Similar finding was obtained in the current study. Good treatment results have also been obtained by inducing maxillary widening prior to the headgear therapy (Fenderson et al. 2004). If the headgear therapy is used without inner bow expansion, some increase in intercanine distance may still be gained, while the intermolar distance is expected to remain unaffected (Ghafari et al. 1994, Ghafari et al. 1998). Keeling et al. (1998) noted, with cervical headgear therapy, a normal forward growth of the mandible even with the prevention of maxillary widening by a maxillary retainer with a bite plane.

In the present study, maxillary and mandibular widening achieved dental arch space. No teeth extractions were needed in any of the treated subjects, despite observed teeth crowding prior to the treatment. Contradicting results were found by Pirttiniemi et al. (2005), who reported the need for extractions in the lower dental arch in 16 per cent of the children treated with the cervical headgear during the late mixed dentition period.

8.2 Lateral cephalometric changes in maxilla, mandible, and facial height

The treated children with Class II malocclusion had a protrusive maxilla at the beginning of the treatment. This was indicated by larger SNA and ANB angles than were observed in 80 Finnish control children with Class I occlusion or 644 unselected Finnish school children with various occlusions (Haavikko 1970). Without treatment intervention in Class II malocclusion, maxillary protrusion and large SNA angles are expected to remain unchanged or increase (Bishara et al. 1997, Ricketts 1960). A protrusive maxilla was treated by restricting the forward growth of the maxillary dental arch, while the rest of the maxilla and the mandible followed normal growth. Class II malocclusion was corrected to a Class I molar relationship, and the SNA angle was decreased. Despite the restricted forward growth of the maxillary A point, the length of the palatal plane (ANS-PNS) grew forward at a normal rate. Therefore, it seems that the treatment restricted the forward growth of the maxillary dental arch and the alveolar process. The maxillary A-point remained virtually unchanged without any forward movement during the treatment period. The other parts of the maxilla were not affected. This contradicts the previously suggested effect of the headgear. Ricketts (1960) found little or no forward movement of the ANS point. Ringenberg and Butts (1970) indicated a growth retardation and distal movement of the maxilla in relation to the anterior cranial base.

Prior to the treatment, the palatinal plane was anteriorly upward inclined in the children with Class II malocclusion. They had smaller NS-ANSPNS angles than the controls (Figures 3 and 6). During the treatment, the palatal plane was rotated downward to reach a position similar to that in the controls. Similar results have been noted earlier (Barton 1972). It has been suggested that this downward rotation is important in the correction of open bite in Class II malocclusion, while other effects of rotation are considered minor. However, Ricketts (1960) suggested that the rotation might be an important factor in the restriction of the maxillary growth. The Class II group of children in the current study had outward inclined maxillary incisors. During the treatment, this inclination was slightly increased despite the downward rotation of the palatal plane. However, since the annual change in the NS-UI angle was similar in the treated children and the controls, the outward inclination during the treatment was not substantial.

Class II malocclusion may be related to mandibular retrognatism (McNamara 1981a Rosenblum 1995). The treated children with malocclusion in this study did not have a retrognathic mandible. In fact, they had even larger SNB angle than the controls both prior to and after the treatment. In Class II treated children, the mandible rotated upward and forward, following the normal growth pattern (Björk 1969, Skieller et al. 1984). Cook et al. (1994) and Lima Filho et al. (2003c) reported similar findings, while earlier studies without maxillary expansion have noted the opposite effect of the treatment on the mandible (Klein 1957, Melsen 1978, Poulton 1967). The Sella-Nasion line was used as the reference in this study. The presence of mandibular retrusion is suggested by the measurement of Downs' facial angle (FrL-NPg) and the SNB angle. In the group of 40 children included in study II, the children with Class II malocclusion had significantly smaller Downs' facial angles (FrL-NPg) both before and after the treatment than the British control children (Bhatia 1993). Unfortunately, McNamara's analysis (McNamara 1984) was not used in the current study to estimate the presence of maxillary protrusion or mandibular retrusion. This was mainly due to the lack of Finnish reference data.

The children in the Class II group had longer facial height (N-Me, ANS-Me) both before and after the treatment. The growth rate of the total facial height (N-Me) was 0.8 mm per year more than in the controls. It is worth noting that, during the treatment, the lower facial height (ANS-Me) grew 0.2 mm per year less than in the controls. Similarly as in the current study, Ringenberg and Butts (1970) found that the headgear treatment had no effect on the facial height.

8.3 Headgear treatment and soft tissue profile

Class II correction had favorable esthetic effects on the facial profile. In the children studied, Class II malocclusion was associated with larger SNA angles and skeletal facial convexity than was observed in the controls. However, this larger convexity was not as evident in the soft tissue profile. The g-sn-pg angle did not differ significantly from that of the controls before or after the treatment. If left untreated, the upper lip and the soft tissue facial convexity are supposed to increase with growth. However, it is possible that some spontaneous decrease can be observed in the skeletal facial convexity (Bishara et al. 1997). By reducing the maxillary protrusion, the treatment decreased skeletal and soft tissue facial convexities, while the rest of the facial structures grew forward normally. The treatment was associated with facially downward rotation of the maxillary palate, together with an increase in nose length. Although the upper incisors became more facially inclined, the nasolabial angle decreased, indicating a decrease also in upper lip protrusion.

The length and thickness of the lips are important elements of the facial profile. In Class II treated children, the relaxed lip position became more closed during the treatment.

Lip protrusion has been shown to be largely affected by the inclination of the incisors (Nanda and Ghosh 1995). Despite the labial inclinations of the upper incisors in the treated children, the nasolabial angle increased, and hence, the upper lip became more upright. The children with Class II malocclusion had thicker and more protruded upper and lower lips than the controls. The treatment did not have a significant effect on this thickness or protrusion. The observed decrease in the ls to sn-pg-line distance may be caused by the straightening of the facial profile rather than by the retraction of the upper lip. Nevertheless, it should be remembered that the lip thickness, in general, decreases from 18 years of age onwards (Burstone 1967, Hellman 1932, Ricketts 1957). Therefore, it may be esthetically beneficial to avoid an overcorrection of the lip protrusion.

Before the treatment in Class II treated children, the palatal plane (ANS-PNS) was inclined facially upward compared with the controls. This inclination may cause an upward cant nose and a short nose length (Bench et al. 1978). Children with Class II malocclusion also had a shorter nose length and a smaller skeletal nose width than the controls. The difference in nose length disappeared during the treatment with facially downward rotation of the palatal plane and widening of the skeletal nasal structures. The treatment had no effect on the growth of the nose depth. This is in accordance with the previous data suggesting that the growth of nose depth is independent of the underlying skeletal growth (Nanda et al. 1990). Overall, the changes in the nose may have led to a more prominent appearance of the nose. Unfortunately, photo-based analysis of the facial appearance was not performed.

8.4 Upper airway structure in Class II malocclusion

The children with Class II malocclusion had a wider than or a similar nasopharynx to the controls, but a narrower oro- and hypopharyngeal space. Oropharynx, in the retropalatal area, was somewhat widened by the treatment, whereas the lower oropharynx and hypopharynx remained narrower than in the controls.

The effects of the treatment on the upper airway space seem to be limited to the nose and oropharynx. The treatment increased the nasal width more than in the controls. Similar changes have been noted by Crouse et al. (1999). This observed increase in the lateronasal width, together with the observed increase in the retropalatal oropharyngeal space, should decrease nasal resistance and enhance nose breathing, although the effect may not necessary be clinically significant (Warren 1990, Warren et al. 1990, Warren et al. 1987). Increased nasal breathing should have favorable effects on dentofacial development (Linder-Aronson 1972, Linder-Aronson et al. 1986, Woodside et al. 1991). The horizontal position of the mandible and the high position of the tongue suggest that the treated children have been nose breathers prior to the treatment. Maxillary widening has been shown to effectively decrease the upper airway obstruction during sleep in children (Villa et al. 2007).

The angle between the palatal plane and the uvula was decreased during the treatment. However, this decrease did not correlate with the changes in dimensions of the retropalatal oropharygeal space. I suggest that at least some of the decrease in this angle is due to the anterior downward rotation of the palatal plane, rather than a change in the position of the uvula.

Hyoid bone was in a higher position in the children with Class II malocclusion than in the controls. Similarly, Abu Allhaija et al. (2005) reported that in Class II subjects the hyoid bone was vertically closer to the mandible compared to Class I controls. Ricketts (1989b) mentioned in his book that habitual tongue thrusters might have the superior position of the hyoid bone. During the first clinical appointment, 40% of the children with Class II malocclusions in this study were observed to be habitual tongue thrusters.

8.5 Treatment time and need for phase 2 treatment

The average age at the onset of the treatment was 9.3 years. The starting age of the treatment did not affect the Class II correction results. All subjects, except one boy, were of mixed dentition stage at the start of the treatment (6.6 to 12.4 years), and hence the treatment response was expected to be consistent within these groups (Bowden 1978a, 1978b).

The average treatment time was 1.7 years, which is comparable to earlier studies (Cook et al. 1994). The needed treatment time varied from 0.3 to 3.1 years. Twenty-three percent (15/65) of children were estimated to show only moderate cooperation, more frequently in boys than in girls ($p < 0.0001$). There was a tendency toward longer treatment times in children with only moderate cooperation (good cooperation 1.6 years, moderate cooperation 2.0 years, $p = 0.09$). The treatment time correlated weakly but significantly with the degree of overjet at the onset of the treatment (R^2 0.11, $p = 0.006$) but not with SNA angle ($p = 0.18$). The treatment times were longer in the first two studies (I, II) than in the remaining three studies (III – V). This is most probably caused by a larger overjet, wider SNA and ANB angles, and smaller SNB angles in the treated children in the first two studies.

In all subjects overjet decreased by 1.9 mm on average ($p < 0.0001$). The overbite did not change considerably during the treatment. Normal overbite (1/3 – 1/2 overlapped) remained unchanged and the deep overbite (>2/3 overlapped) either remained the same or was decreased, edge-to-edge overbite was changed to normal overbite in four out of six subjects.

Phase 2 treatment was needed in 52 % (34/65) of the treated children, most often because of excess overjet or overbite. Pirttiniemi et al. (2005) found that 27 % of their cervical headgear group needed fixed appliance therapy, and 16 % of the cervical headgear group patients needed extractions in the lower arch. None of the patients in the present study needed extractions. The timing of the Class II correction treatment may be one reason for the different need for phase 2 treatment and extractions of permanent teeth.

8.6 Molar extrusion

The headgear therapy has been claimed to produce upper molar extrusion (Baumrind et al. 1983, Baumrind et al. 1981, Baumrind et al. 1978, Klein 1957, Melsen 1978, Poulton 1967, Ricketts et al. 1979). However, the current study, together with the study by Cook et al. (1994), shows that this extrusion may be prevented if upward-bent outer bows are used. This bending supposedly elevates the resultant force of the cervical traction above the center of resistance of the upper molars, thus preventing the eruption. In the present study, the long outer bow was bent 15° upward as recommended by Bench et al. (1978), not 20° as recommended by Cook et al. (1994). The bending of the long outer bow of the headgear even further upward increases the risk for first molar tipping.

8.7 Study limitations

The important limitation of the current study is the lack of a real control group. Therefore, for the comparisons normal values were used either from the literature presented by Moorrees (1959), Riolo et al. (1974), Huggare et al. (1993), Bhatia and Leighton (1993), Athanasiou et al. (1992), or cephalograms taken from the Finnish cohort collected by Haavikko (1970).

All control cohorts had been collected well before this study. During the past few decades, there has been a significant tendency toward narrower dental arch dimensions of mixed dentition (Defraia et al. 2006, Lindsten et al. 2001). Therefore, the comparison to significantly older control groups is not necessarily valid.

The Finnish control group (Haavikko 1970) was used in two different ways. First, all cephalograms were analyzed and the results were combined for each year group (Figures 6, 7, and 9). Second, eighty controls with Class I molar relationship were blindly selected from this normal population. To enable the direct comparison between the two studied groups and to minimize the effect of normal variability within the control group, the normal growth pattern of each parameter was estimated by fitting a fourth-order polynomial equation to the control group data (Figures 6, 7, and 9). This calculated fitted mean was used to estimate the normal mean value for each particular age, and the annual change in each parameter within the control group. A more precise estimate of normal growth would have been valuable but this would have required a substantially larger and newer control population or a longitudinally followed control group.

Posteroanterior (PA) cephalometry was used to estimate the effects of the treatment on skeletal facial and dental widths. The use of PA cephalometry is not as standardized as the use of lateral cephalometry. This causes problems especially in the use of different magnifications. The comparison to the control values was limited by the fact that the control measurements were reported without any correction factor. This problem was overcomed with two different approaches: first, I contacted Professor Athanasiou directly and received the used correction factor directly from him. Secondly, my results were compared as ratios of measured widths over the latero-orbital distance (lo-lo) to control values previously reported by Athanasiou et al. (1992). The latero-orbital distance is relatively constant in older children, and therefore it is probably not affected by treatment interventions. In the studied children, this distance grew by only 0.6 mm/year. I assume that the most exact way to correct the measurements would be to use the method described by Hsiao et al. (1997). Therefore, the values were reported also by using this method.

9. CONCLUSIONS

The cervical headgear was used successfully, without other appliances, for the correction of Class II malocclusion in school-aged children presenting with Class II division 1 malocclusion and protrusive maxilla. Half of the children needed phase 2 treatments because of remaining overjet or overbite. The method is simple and only short control visits were needed.

The headgear treatment significantly reduced the SNA angle and the facial convexity. Despite significant inhibition of the forward growth of the maxilla at the level of the A-point, the rest of the maxilla grew forward at the same rate as in the controls. The palatal plane was rotated facially downward, while the maxillary incisors became more facially inclined. This reduced the beneficial effect of the palatal rotation on facial convexity. The mandible grew forward at the same rate as in the controls. The headgear was used with the expanded inner bow. This led to a significant widening of the maxillary and mandibular dental arches, as well as the nasal width. I suggest that the maxillary widening was a key factor for the treatment success.

The skeletal and soft tissue changes produced by the headgear treatment are in line with what is generally considered as esthetically beneficial. However, even at the onset of the treatment, the soft tissue differences between the controls and the children with Class II malocclusion were milder than the skeletal differences. Therefore, to a significant degree, soft tissue masks the underlying malocclusion and the skeletal abnormalities.

Children with Class II malocclusion had somewhat narrower oro- and hypopharyngeal spaces than the controls. The headgear treatment increased the nasal width and retropalatal airway space to some degree, but did not significantly affect the rest of the upper airways.

The results presented in this thesis support the early use of headgear treatment with the expanded inner bow for Class II correction in children.

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